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April 2011
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Accelerating Software Modernization
with Artificial Intelligence

AI is radically transforming the way organizations evolve their software assets to achieve competitive advantage.

Artificial Intelligence (AI) is the quest to achieve computers that equal or exceed human performance on complex intellectual tasks. A phenomenal development in AI is the recent emergence of automated computer language translation programs, driven by the need to modernize the nearly half trillion lines of legacy software developed during the latter half of the 20th century.

Early software translators of the 1990s, like the earliest chess programs, were disappointing and limited. Leveraging AI technologies that evolved from the 1980s era USAF's Knowledge Based Software Assistant and emerging standards, computers can now understand and translate software applications with levels of proficiency that vastly exceed human performance. This technology is revolutionizing the way industries, such as finance, insurance, manufacturing, and healthcare as well as military and governments are modernizing their legacy systems.

Leading this field is The Software Revolution, Inc. (TSRI), a Kirkland, Washington based company. Building upon 32 years of continuous R&D, TSRI's robust *JANUS* Studio® tool suite provides large-scale, error-free legacy system modernizations at 100% levels of automation. By applying AI to abstract software models, TSRI delivers automated code conversion with unprecedented target code quality, economies of scale and schedule compression, accomplishing with small teams in months what would take years by other means. The following list of brief case studies represents five recent TSRI legacy system modernization projects.

- **European Air Traffic Management System (EATMS), Thales Air Systems:** This realtime system manages over 10 million passenger flights annually. Thales engaged TSRI to transform EUROCAT's 2 million lines of legacy Ada into Java. The result was a perfect functional replica of EUROCAT in its new language. TSRI's 100% automation eliminated the risk of errors inherent in a manual rewrite. EUROCAT will commence operation in significant airports across Europe and Asia at the end of 2011.

- **Patriot Missile, Fire Platoon Simulation & Battalion Simulation Support Systems, Raytheon:** TSRI used the *JANUS* Studio® tool suite to modernize four different Patriot systems including Patriot Japan. These modernizations included the transformation of nearly 200 thousand source lines of Fortran code to C++, re-factoring and documentation.

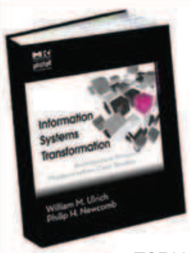
- **Major Healthcare Insurance Company:** This system consisted of over 180 thousand source lines of PowerBuilder and nearly 3 million lines of COBOL. In modernizing this system TSRI provided transformation, re-factoring and supported system integration. This project was completed in only 15 months.

- **Major US Bank:** This legacy application contained over 3 million source lines of Fortran and over 160 thousand lines of DCL. TSRI automatically generated a *Transformation Blueprint*™ to assist in the systems design architecture, performed the code documentation and provided engineering support.

- **Advanced Field Artillery Tactical Data System (AFATDS), Stanley and Associates (Now CGI Federal):** A version of the US Army's legacy AFATDS system consisting of over 5 million source lines of ADA-83. TSRI employed *JANUS* Studio® to transform this system into Java in only 10 months. TSRI delivered the modern system to Stanley in August 2010.

Information Systems Transformation: *Architecture-Driven Modernization Case Studies* provides more detailed information on these case studies.

For more information visit www.tsri.com



Information Systems Transformation:
Architecture-Driven Modernization Case Studies
By William M. Ulrich and Philip Newcomb
ISBN: 978-0123749130

About the book:
Architecture-Driven Modernization (ADM) gives you everything you need to know to update costly obsolete systems, transform data, and save millions of dollars.

Philip Newcomb
Founder and CEO of TSRI

Mr. Newcomb is an internationally recognized expert in the application of AI and formal methods to software engineering. After leaving Boeing he led a team of software engineers to develop TSRI's *JANUS* Studio® tool suite. Mr. Newcomb is the author of numerous papers, books and industry standards.

TSRI is a Platform Member of the OMG and leading contributor to the ADM Task Force (ADMTF) standards. TSRI's services and *JANUS* Studio® tool suite have served as the leading exemplar for the OMG's emerging ADMTF standards.

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COVER
A device called a Square attaches to an iPhone and allows merchants to process credit cards. In 2011, mobile payments are expected to total $119 billion worldwide.
Photograph by Toby Burditt

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Letters and Comments

ISSUES WITH ELECTRIC VEHICLES

"Will Electric Vehicles Finally Succeed?" (January/February 2011) ignores a key issue. Lithium-ion batteries exhibit a limited number of deep discharge cycles, and a car like the Chevy Volt can go roughly 35,000 to 40,000 miles before it needs a new set. Chevy will replace the batteries up to 100,000 miles, but that doesn't come free. The cost runs up to 25 cents per mile, making electric cars far more expensive per mile than hybrids. New battery technology is coming along that may make electric-vehicle miles less expensive, but it is not available now, nor will it be in the near future.

Eugene I. Gordon
Mountainside, New Jersey

Although very informative with regard to the automotive technology, "Will Electric Vehicles Finally Succeed?" did not address several issues that I believe will doom any effort by electric cars to make large-scale inroads into the automobile market.

The first issue is power demand. Utilities in the United States today can barely keep up with current domestic and industrial usage, let alone any projected increases. Should breakthroughs in battery technology be realized and electric-car sales soar, where will the electricity come from? We are building very few major power plants, and "alternative" sources aren't even close to contributing significantly to the power supply.

The second issue is overall efficiency. Today's gasoline-powered cars run at about 20 percent thermal efficiency; diesel models can approach 35 percent under ideal conditions. Even if electrics with new batteries can achieve, say, 80 percent efficiency, the electricity that powers them is generated at about 41 percent fuel efficiency (80 percent by fossil plants at 33 percent efficiency and the remainder by nuclear). Although state-of-the-art combined-cycle plants can achieve efficiencies of up to 50 percent, these make up just a small part of our national infrastructure. Add in transmission and distribution losses of about 5 percent, and only about 36 percent of the fuel burned ends up being delivered to the power outlet for the car. Include the car's efficiency factor and the result is not much better than for gasoline, and not as good as the figure for diesel.

Electric cars thus reduce overall carbon dioxide emissions only minimally, but at significant cost not only for the cars themselves but for the utilities required to support them.

Ted Williams
Gloucester, Virginia

MEDICINE'S AGE OF ENGINEERS

The human genome represents the ultimate software puzzle that defines humanity ("The Human Genome, a Decade Later," January/February 2011). Completion of the Human Genome Project brought medical science to a crossroads at which it began to require the support of engineers. Made up of three billion pairs of the nucleotides (or bases) adenine (A), cytosine (C), guanine (G), and thymine (T), the human genome is a computer program written in a language of which less than 6 percent has been deciphered. Analogous to the difficulty facing medical science would be an effort to decipher a string of three billion *1*s and *0*s without intimate knowledge of instruction code and how programs, reference tables, or data files are written.

We must aggressively apply what we know about computer programming and computer hardware design toward mapping out DNA, defining cellular operations, and interfacing with human brain function. Medicine will progress no further until we accomplish this task. The most prominent obstacle to developing meaningful medical therapies is the language-knowledge barrier that exists between medical science and engineers. Once it's overcome, medical therapies will be limited only by the number of diseases in existence and the imagination of engineers.

Lane B. Scheiber
Grosse Ile, Michigan

January/February 2011

NEW MODEL NEEDED FOR TV

Google does not address what I believe many people are looking for: an alternative to the traditional model of delivering video content ("Searching for the Future of Television," January/February 2011). The cable and satellite-dish models deliver tens if not hundreds of channels that most people couldn't care less about—"junk TV." I would prefer an "à la carte" model where I get to pick and choose the content—not just accept what the cable companies choose to deliver. It might even save us some money. My cable bill just went up again, and the reason the cable company gave was "increased programming costs,

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new innovative features, and infrastructure maintenance." I say it's time to revolutionize the way video content is delivered and consumed.

John Caporal
Norwich, New York

DO DISREGARD NUCLEAR

On the letters page of the January/February 2011 *Technology Review*, responding to Matthew Wald's story "Giant Holes in the Ground" (November/December 2010), James Hopf writes that "In any fair competition among non-emitting sources, nuclear would do very well." It is my opinion that the nuclear industry has the ethics of the tobacco industry. It routinely lies and presents misleading information to the public. For the nuclear physicists in the audience: The industry says that nuclear waste will decay to unharmful levels in a few hundred years. While that may be true for products of nuclear fission, it is most definitely not true for the products of neutron capture. They take millions of years to decay back to the levels of the uranium they initially came from.

The industry claims that it can compete with renewable energy sources if only the government would refrain from subsidizing greener alternatives. Not true. Nuclear power receives a subsidy that is literally of incalculable value. It is the Price-Anderson Act, which caps industry liability from nuclear incidents at $10 billion. Anything higher would be covered by the federal government. Without this subsidy, the nuclear industry in the United States would go out of business tomorrow.

Frank J. Weigert
Wilmington, Delaware

Correction: In "Will Electric Vehicles Finally Succeed?" (January/February 2011), a caption incorrectly labeled a part in the Nissan Leaf as an inverter and said it converts AC power to DC. That conversion is performed by a rectifier; the part in question contains a rectifier and an inverter.

Is WikiLeaks a Good Thing?

By itself, perhaps not. But as an innovator, maybe.

In this issue of *Technology Review* we describe and celebrate the 50 most innovative companies in the world *(p. 35)*. Neither described nor celebrated among the TR50 is WikiLeaks, the Internet organization that publishes the secrets of governments and businesses, because it is neither a company dedicated to generating profits nor, perhaps, a fit subject for celebration. But WikiLeaks is, for all that, the most interesting Web startup around.

In "Transparency and Its Enemies" *(p. 70)* I have tried to make sense of the organization and its guiding spirit, Julian Assange. What WikiLeaks is, and whether it is good or bad for civil society, has become disputed terrain; and what has been written tends to reveal the authors' feelings about authority more than it illuminates the organization's innovations. Yet those innovations are real and disruptive and, like those of any Web startup, can be imitated by other, perhaps more sustainable ventures with better modes of business.

In my review I define WikiLeaks and separate its technology from Julian Assange's goals, which are, he has written, "to induce fear and paranoia in ... [the] leadership and planning coterie" of "conspiracies"—by which he means the management of modern states and corporations. I suggest that his creation may not survive very long, because the state, with all its powers, will resent any attempt by an avowed enemy to explode its mysteries. I argue that the organization's technology—the "secure drop box," which I call a "'platform' from which leaks cannot be traced and cannot be censored"—once imagined cannot be forgotten, and will be replicated by more conventional media organizations like the *New York Times* and Al Jazeera, as well as by other, less radically activist organizations dedicated to leaking. One disgruntled former WikiLeaks volunteer, Daniel Domscheit-Berg, has said he will create a competing, less politically threatening platform called OpenLeaks. Others are sprouting up.

Is all this a good thing? In writing my review, I evaded any moral or political judgment, but the question preoccupied me.

Any answer will reflect the writer's preferences. Personally, I distrust transparency. I am by birth and education a member of the establishment, and politically a Whig (that is, a sort of progressive conservative). I think the rights we enjoy are not natural but derive ultimately from the laws of a properly constituted state, and I am wary of attacks upon its institutions. I believe that states and corporations, like individuals, enjoy some privacy rights and that any human system requires secrecy for its effective management. Neither innovations, nor art, nor contracts, nor representative government, nor marriages, nor many other valuable things would exist without secrets.

More, I am confident that we know how secrets should be kept. The computer scientist Jaron Lanier recently wrote an article called "The Hazards of Nerd Supremacy: The Case of WikiLeaks." There he insisted, "If the secret is of vital interest to other people, then secrets can be kept by those who are sanctioned and accountable to keep them within the bounds of a reasonably functional democratic process." I think that's about right.

At the same time, *of course* I am conflicted. As a journalist, I am committed professionally to truth-telling. Often that means revealing the secrets of the powerful, who, understandably, resist public embarrassment and would prosecute the publication of leaks as treason or theft if they could. Therefore, I cling to the formal protections that let me publish such secrets without risk. Lanier's reasonably functional democratic process requires for its operations that I should be free to practice a kind of licensed disrespect for the ordinary laws governing secrecy.

Justice Hugo Black, explaining the Supreme Court's decision in 1971 to allow the *New York Times* to publish the Pentagon Papers (which showed that the U.S. government had misled the American people about the origins, scope, and progress of the Vietnam War), wrote, "Only a free and unrestrained press can effectively expose deception in government." It was true then, and it is truer now. Secrets breed like weeds, and all over the world they have grown to occlude everything that is done by those who govern us or sell us things; technology has made it easier for states and corporations to keep such secrets; and a corrective toward transparency is long overdue. Thus, I welcome the use of secure drop boxes by recognizable media organizations, or neutral organizations that wish to work with them.

Just as we balance equality and freedom, we must balance the conflicting goods of secretiveness and transparency. I don't like Julian Assange's goals and methods, but corrective reformers are mostly unlikable weirdos.

But write to me at jason.pontin@technologyreview.com and tell me what you think.

—Jason Pontin

MARK OSTOW

notebooks

ENERGY

Curbing Carbon

New energy technologies need the support of sound economic policy to prevent further damage to our climate, says Robert N. Stavins.

Throughout the U.S. economy, millions of decentralized decisions are made every day that contribute to the problem of climate change. A national carbon-pricing system—in the form of either carbon taxes or cap-and-trade—is the only policy that can significantly tilt them all in a climate-friendly direction. Given the ubiquity and diversity of energy use in a modern economy, conventional regulatory approaches simply cannot do the job.

Furthermore, carbon pricing is the least costly approach. In the short term, the cost of reducing emissions will vary wildly across sources as different as coal-fired power plants and cars and trucks. Only carbon pricing provides strong incentives that can push all sources to control at the same marginal cost, achieving the lowest possible expense overall. In the long term, it will create incentives to develop carbon-minimizing technologies *(see "Praying for an Energy Miracle," p. 46)* that reduce costs over time.

But carbon pricing cannot fix all the market failures that are causing our climate's problems. It must work alongside policies that foster climate-friendly technology research and development if we are to bring carbon dioxide emissions under control.

The most important failure that carbon pricing cannot address is the fact that firms pay the costs of their R&D but do not reap all the benefits. Even if intellectual-property rights were perfectly enforced, tremendous spillover benefits would accrue to other firms. Inventions and innovations by one firm provide valuable information that leads to new inventions and innovations by other firms.

Thus the information created by R&D is what economists describe as a "public good," benefiting actors entirely external to its place of origin. A rational response from the private sector is to carry out less than the "efficient" amount of research into new climate-friendly technologies, even under carbon pricing. Hence, other public policies are needed to address this failure of the R&D "market."

Public support will be necessary to develop new technologies to combat climate change. And to address the climate-change market failure itself, carbon pricing will be necessary. This is an application of a fundamental principle in economics: two market failures require the use of two policy instruments. Empirical economic analysis has repeatedly verified that combining carbon pricing with R&D support is more cost-effective than adopting either approach alone.

Both carbon pricing and direct technology-innovation policies are necessary. Neither is sufficient. These are complements, not substitutes.

ROBERT N. STAVINS IS THE ALBERT PRATT PROFESSOR OF BUSINESS AND GOVERNMENT AT THE HARVARD KENNEDY SCHOOL, A RESEARCH ASSOCIATE OF THE NATIONAL BUREAU OF ECONOMIC RESEARCH, AND A UNIVERSITY FELLOW OF RESOURCES FOR THE FUTURE.

INNOVATION

Users Rule

Novel products that create new markets often emerge from pioneering user inventions, argues Eric Von Hippel.

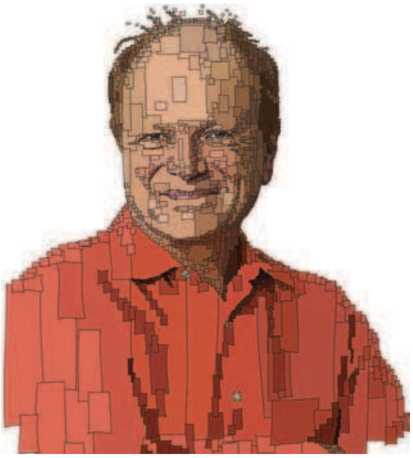
Sometimes pioneering innovation comes from a company offering a new product or service—a number of examples are featured in this issue *(see "The TR50," p. 35)*. But these producers, and those to come, will do their jobs better if they understand a lesson my colleagues and I have learned in our research: users of a technology, whether they're individuals or companies, are usually the initial developers of important innovations that enable them to do new things and create new markets.

Twitter is one example. Its community of users invented retweets and hashtags, both now core parts of the service. Similarly, major equipment users such as Western Electric, IBM, and Intel initially developed important processing techniques now embodied in equipment sold by Applied Materials. Users excel at this role because they understand their emerging needs better than producers do.

The pattern holds true in emerging as well as developed economies. For example, the idea of banking by cell phone first emerged in the Philippines, Kenya, and other countries poorly served by banks. The service is enabled by wireless carriers, but the innovation originated when users without bank accounts began to buy credits for cell-phone minutes and exchange them between phones to settle financial transactions. From that developed a major business.

Working with Harvard Business School's Christoph Hienerth and Copenhagen Business School's Carliss Baldwin, I've studied the ways that user-developed innovations become commercial products or services. The process begins when one or more lead users recognize

NICK REDDYHOFF



a need for a product that does not yet exist, whether it's the first skateboard or the first heart-lung machine. Users then experiment to make prototypes of that new product. If they tell producers at this stage, they are typically rebuffed on the justifiable grounds that "there is no market for that." Only after other users from the community have started to experiment, too, and perhaps even started their own ventures to commercialize those experiments, does the potential of the new market become clearer to everyone. At that point, additional startups and established firms join in.

The transition to digitized and modular design practices, coupled with low-cost Internet-based communication, increasingly allows user innovation to compete with producer innovation in many parts of the economy, all over the world. Open collaborative innovation in software development communities such as Linux is well known today. Similar activity in arenas ranging from sports to medicine to car development is less well known but growing rapidly.

Firms that want to innovate successfully must learn to understand their own role in this innovation ecosystem. Superior knowledge of the pathway from user innovation to commercialization can bring a producer larger profits and the chance to develop technologies that create entirely new markets.

ERIC VON HIPPEL IS PROFESSOR OF TECHNOLOGICAL INNOVATION AT THE MIT SLOAN SCHOOL OF MANAGEMENT AND A PROFESSOR OF ENGINEERING SYSTEMS AT MIT.

COMPUTING

Web Wins

Håkon Wium Lie says that Web apps can displace all other forms of software if browser and Web technology continue to improve.

The next big battle in the world of computing will pit applications that live on the Web against the kind that live on a computer.

For several reasons, it would be beneficial if Web apps were to win. One reason is that the Web has a much broader reach than any other platform: Web browsers run on all kinds of devices, from mobile phones and tablets to game consoles and laptop computers. Another is that Web languages are developed by standards organizations like the World Wide Web Consortium (W3C) rather than being controlled by individual corporations.

However, conventional applications may retain the edge in performance. That's because they are built from "native code" that runs closer to a device's hardware. It can, at least in theory, run more optimally than Web code that needs to be interpreted by extra layers of software before hardware can act. For the user, that can translate into the difference between a smooth animation and a stuttering one. Besides, mobile devices have limited memory, battery power, and numbers of processor cycles.

Nevertheless, I think that Web apps will soon be able to compete with native apps, for two reasons.

The first has to do with the use of JavaScript, a Web programming language that provides fluid, dynamic user interfaces. The speed at which a Web browser's JavaScript engine could translate this code was at one time a bottleneck constraining the performance of Web applications, but browser makers are now competing fiercely to make better JavaScript engines. Modern engines like the ones inside Opera, Chrome, Safari, and Mozilla Firefox have been optimized to the point that JavaScript no longer holds back most applications *(see "The Slow-Motion Internet," p. 54)*.

Second, up-to-date Web languages such as HTML5 and CSS3 will handle many computing-intensive tasks that have been difficult for Web apps. For example, HTML5 makes it easy to integrate video into these applications. Current Web browsers ship with video codecs, and decoding is increasingly supported

by hardware. Animations provide another example. In the past, devices fast and slow were forced to play every frame of an animation, whether or not they were capable of doing so smoothly. Now a designer can use CSS3 to define start and end points for an animation and leave the Web browser to interpolate the frames in between. A mobile device may show fewer frames than a desktop computer, but both will run the animation as smoothly as they can.

If such advances can allow Web browsers to offer the same functionality and performance as past proprietary platforms, the Web will win out. Native apps will become a footnote in the history of computing.

HÅKON WIUM LIE IS CHIEF TECHNOLOGY OFFICER OF OPERA SOFTWARE AND WAS A MEMBER OF THE TR100 IN 1999.

TR50

SPECIAL EVENT:
Secrets of success from top innovative companies

Join Technology Review and MIT Enterprise Forum of NYC for an evening of networking and discussion as we celebrate the 2011 TR50—Technology Review's annual selection of the 50 most innovative companies in the world.

Technology Review's Jason Pontin will moderate a panel with select leaders of 2011 TR50 companies. Confirmed speakers as of February 2, 2011, include **David Berry**, co-founder, **Joule Unlimited** and **David Vieau**, president and CEO, **A123 Systems.**

Date: Tuesday, March 15th, 2011

5:30 p.m. - 6:00 p.m.: Registration and welcome reception

6:00 p.m. - 7:30 p.m.: Panel discussion

7:30 p.m. - 8:30 p.m.: Networking reception

Place: New York Academy of Sciences

250 Greenwich St, #40
New York, NY 10007

Registration:
Free to members of MIT Enterprise Forum
$50 non-members, $10 extra at door
All members and guests are welcome.

Learn more and register online at: bit.ly/MITEF-TR50
Check website for updated speaker list.

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NINTENDO

COMPUTING

Handheld 3-D

Nintendo's portable game console will let users play games in 3-D without wearing special glasses. The key is an autostereoscopic display, which delivers a separate image directly to each eye. Because these displays work best over narrow viewing angles, they are much better suited for mobile devices than they are for televisions.

Product: 3DS **Cost:** $250 **Availability:** March 27 **Source:** www.nintendo.com **Company:** Nintendo

ENERGY

Power Walking

THIS USB CHARGER can be carried vertically in or on a backpack to harvest energy from walkers' footsteps. Electricity is generated by linear induction, as in a shake flashlight. High-efficiency energy harvesting and storage mean the device can gather enough charge for small portable electronics such as an iPod or GPS.

Product: nPower PEG **Cost:** $160 **Availability:** Now **Source:** www.npowerpeg.com **Company:** nPower

COMMUNICATIONS

High-Definition Wi-Fi →

THIS WI-FI ROUTER uses four antennas to constantly retune its radio signal and reshape it by exploiting constructive and destructive interference between them. It can send a focused beam toward distant users who might otherwise get a weak connection. The resulting coverage area is five times the size of those achieved with earlier Wi-Fi systems, and the wireless network can have up to twice the speed.

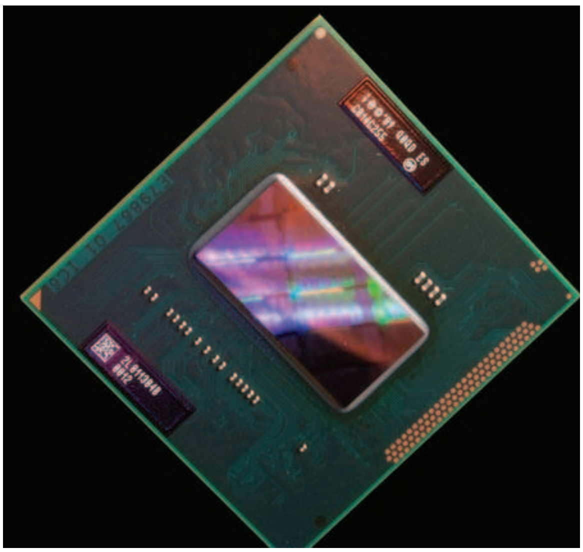
Product: 3DHD Wireless Home Theater Networking Kit **Cost:** $260 **Availability:** Now **Source:** www.netgear.com **Companies:** Netgear, Quantenna Communications

COMPUTING

Skiing by the Numbers

SERIOUS SKIERS often want to know things like their speed and their vertical rate of descent. A GPS-based display mounted in these goggles shows such information in the corner of the wearer's eye; data can later be uploaded to a computer to show the exact route taken during a run.

Product: Transcend SPX Glasses **Cost:** $400 **Availability:** Now **Source:** www.reconinstruments.com **Companies:** Recon Instruments, Zeal Optics



COMPUTING

Graphic Appeal

INTEL'S NEW CHIPS for personal computers include graphics circuitry alongside the processor cores. This lets the cores and the graphics system share high-speed memory and communicate with less delay. Targeted at video-hungry users, the resulting CPU offers features such as rapid transcoding of video files to prepare them for downloading to a mobile device.

Product: Second Generation Intel Core processors **Cost:** About $1,000 for i7 version **Availability:** Now **Source:** www.intel.com **Company:** Intel

ENERGY

Smart Cooking

PUTTING SMART meters in homes is a first step toward the smart grid, but people are unlikely to check the meter every time they want to heat up a pizza. Appliances like this electric stove, however, communicate wirelessly with the smart meter and adjust their behavior automatically: for example, during peak consumption hours it might default to its smaller, less-energy-demanding upper oven. Owners have the option of overriding these electricity-saving choices.

Product: Brillion double oven
Cost: Not available
Availability: Through utilities in 2011, mass market in 2012
Source: www.geappliances.com
Company: General Electric

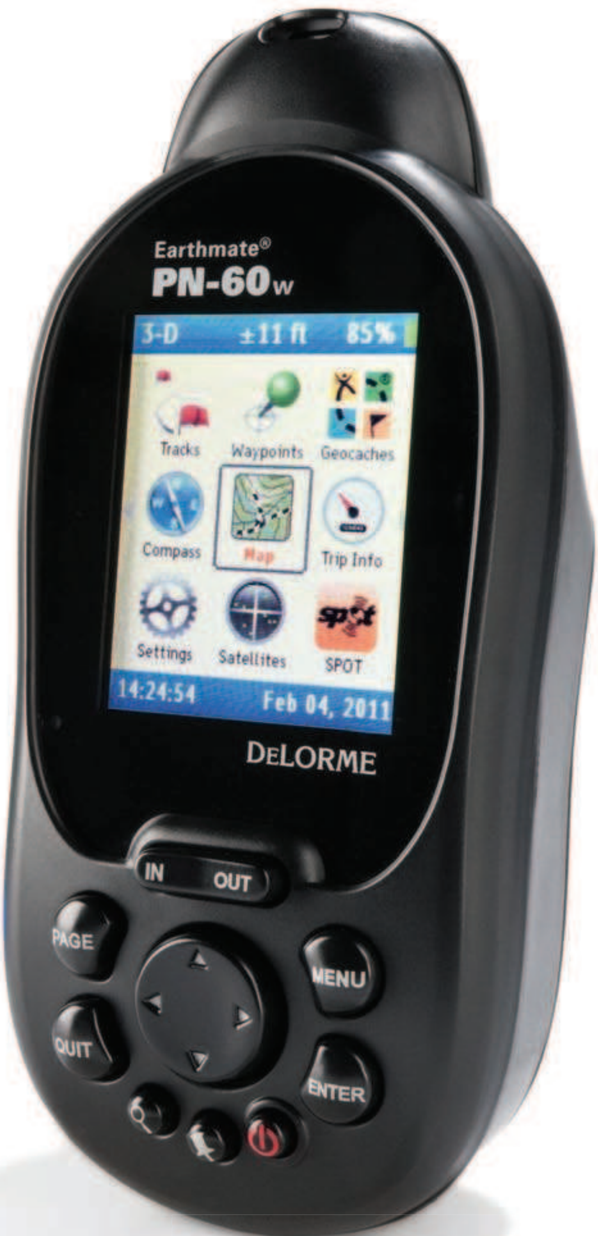
COURTESY OF NPOWER (PEG); INTEL (CHIP); NETGEAR (WI-FI); RECON (GOGGLES); GE (STOVE)

MATERIALS

A Taste of Science

CHEWING GUM can make a mess out of carpets, clothes, and sidewalks, largely because the water-resistant polymer used as a base for most gums is very sticky and doesn't degrade easily. But Rev7 gum uses a different polymer that doesn't stick as strongly to surfaces and degrades into a water-soluble material that can be washed away. It was developed with the help of research conducted by the University of Bristol in England.

Product: Rev7
Cost: $1.20 to $1.40
Availability: Now in the United States; waiting for EU approval
Source: www.revolymer.com
Company: Revolymer



COMMUNICATIONS

Texting by Satellite

AIMED AT USERS who are often out of range of cell-phone networks but don't want the expense of a full-fledged satellite phone, this GPS system comes with a satellite uplink that makes it possible to send short messages—perhaps to Facebook if an expedition is going well, or to emergency services if it isn't.

Product: Earthmate GPS with SPOT **Cost:** $550 **Availability:** Now **Source:** www.delorme.com **Company:** DeLorme

MATERIALS

Battery-Powered Spectacles

THESE GLASSES FOR people who wear bifocal or progressive lenses use an electroactive layer to switch rapidly between two focal lengths. The wearer can switch the length manually, or the glasses can be set to change automatically as the eyes move: looking down would set them for reading, while looking up would make them suitable for driving.

Product: emPower glasses **Cost:** Approximately $1,200 **Availability:** Late 2011 **Source:** www.pixeloptics.com **Company:** PixelOptics

COURTESY OF UNIVERSAL POWER GROUP (SOLAR); CHRISTOPHER HARTING

COMPUTING

Drowsiness Detector

THIS DEVICE, designed to sit on top of a car's dashboard, periodically checks to determine whether the driver is too fatigued to continue driving safely. It beeps occasionally, prompting the driver to tap the device. Slow response times, combined with driving data from the device's sensors, will trigger an alert if the detector thinks it's time to take a break.

Product: Anti-Sleep Pilot **Cost:** $250 **Availability:** Now in Denmark, later this year in the rest of the world **Source:** www.antisleeppilot.com **Company:** ASP Technology

ENERGY

Powering Sockets with Sunlight

THIS PORTABLE folding solar panel and battery pack can be charged either from a wall socket or by allowing it to collect sunshine for 12 hours. Since it has four 120-volt AC sockets, a fully charged system could power a cordless phone, printer, laptop, and router—for as long as 10 hours. Up to 1,800 watts of power can be drawn at once, so bigger appliances (such as a fridge) could be run for shorter periods of time.

Product: Eco O1800S
Cost: Unavailable
Availability: Spring 2011
Source: www.goecotricity.com
Company: Universal Power Group

graphiti

World of Ideas

Some countries generate more inventions than their economic stature might indicate.

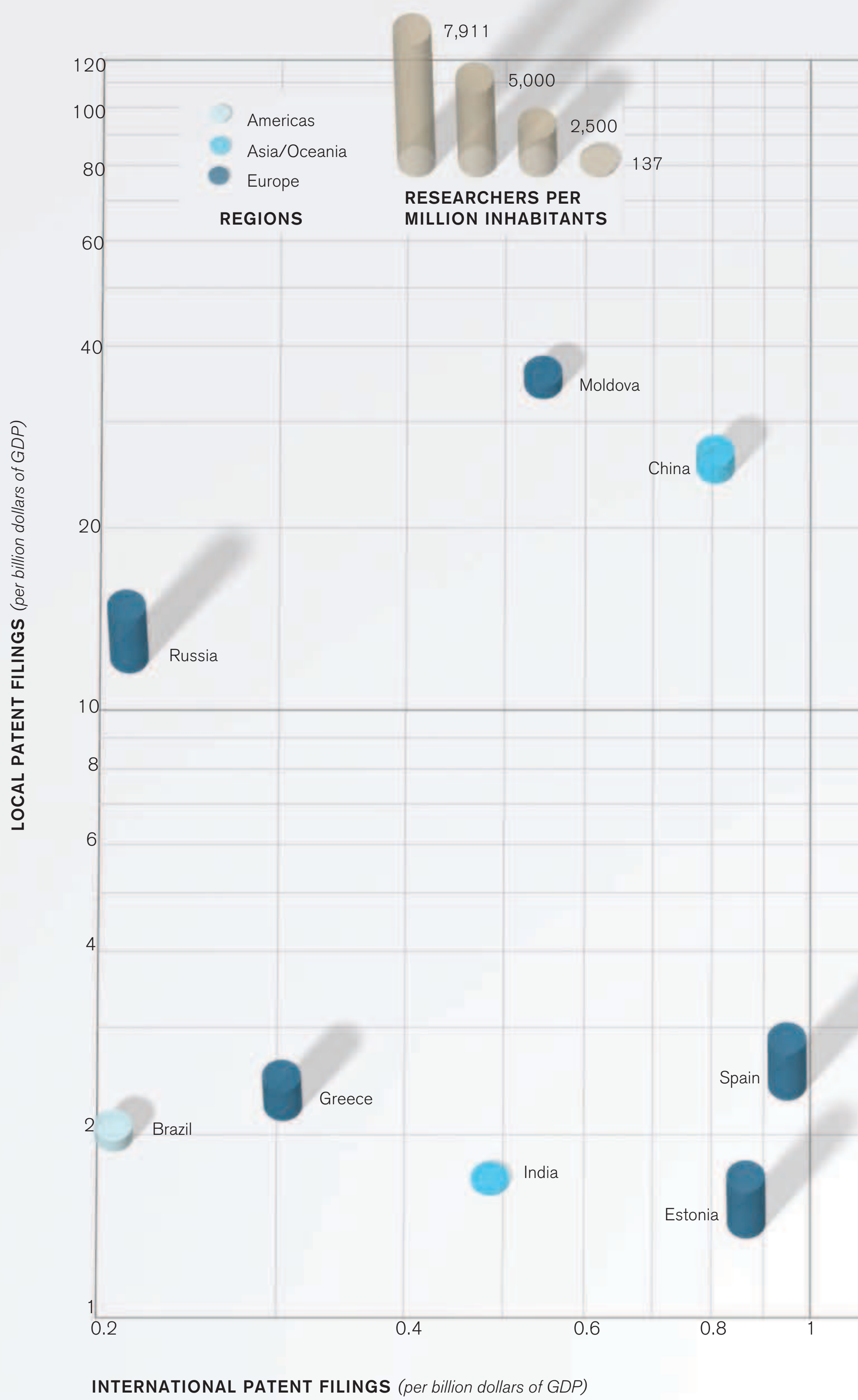
Which country is more devoted to inventing things—the United States or Moldova?

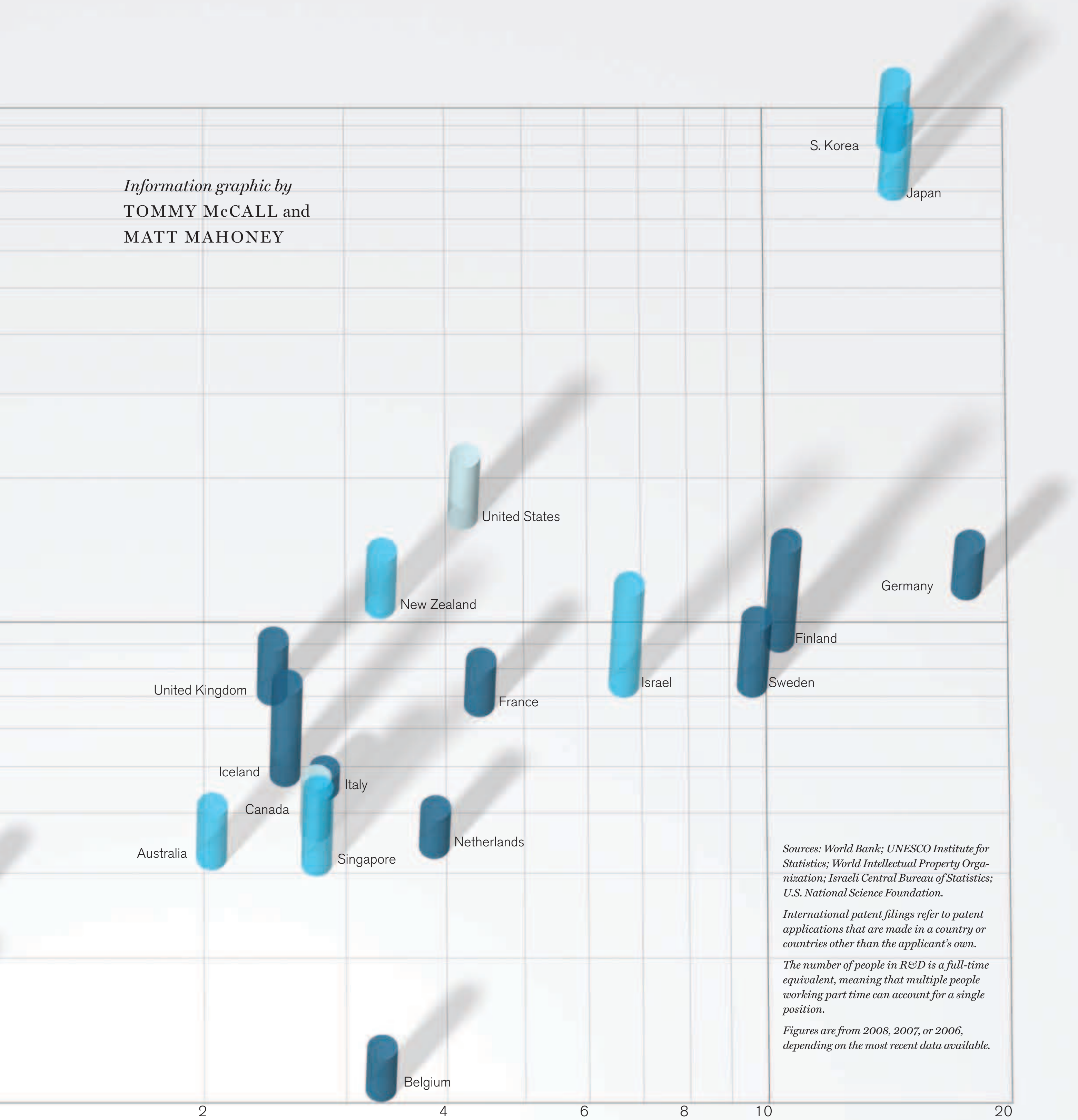
We crunched data for dozens of countries to see which ones generate an outsize number of ideas, relative to their economic might or R&D resources. After eliminating countries below certain thresholds, we plotted the results here.

In countries that are higher on the graph, residents file more patents for every dollar of GDP. In countries that are further to the right, residents apply for proportionally more international patents, which tend to be more valuable because they cover multiple markets. The height of each country's bar reflects the percentage of its people employed in R&D.

So people in Moldova, one of the poorest countries in Europe, apply for relatively more patents, but Americans have a much greater tendency to target multiple markets. Meanwhile, Finland has a higher percentage of R&D workers than either country.

Admittedly, this is an imperfect gauge. Some patents are far more important than others. And some countries require applicants to combine related inventions in one filing. But it's a reminder that inspiration flickers everywhere. —*Brian Bergstein*





Information graphic by
TOMMY McCALL and
MATT MAHONEY

Sources: World Bank; UNESCO Institute for Statistics; World Intellectual Property Organization; Israeli Central Bureau of Statistics; U.S. National Science Foundation.

International patent filings refer to patent applications that are made in a country or countries other than the applicant's own.

The number of people in R&D is a full-time equivalent, meaning that multiple people working part time can account for a single position.

Figures are from 2008, 2007, or 2006, depending on the most recent data available.

Q&A

Jonathan Rothberg

The founder of Ion Torrent says his DNA-sequencing technology will revolutionize genomics the way the microprocessor transformed computing.

Reading the sequence of DNA in a human genome cost about $1 million in 2007. Now it costs $10,000 to $20,000. The ability to cheaply sequence large volumes of DNA has already led to the discovery of new disease genes and improved our understanding of evolution and human history. But Jonathan Rothberg, founder of Ion Torrent, says that DNA sequencing is on the brink of another transformation—and this time its impact will be much more personal.

Rothberg likens the state of genomic technology to that of computing before PCs. And in much the way that the microchip made personal computers and smart phones possible, Rothberg predicts, Ion Torrent's small, cheap machine will allow sequencing to seep into medicine, agriculture, and energy.

50

Ion Torrent's tabletop machine costs $49,000, about a 10th as much as other "next-generation" sequencers. It uses a disposable $250 chip that is fabricated in microprocessor foundries. Industry leader Life Technologies acquired Ion Torrent for $375 million in 2010.

Rothberg recently told *TR*'s biomedicine editor, Emily Singer, why he has such high expectations for his product.

_TR_: How will this technology transform medicine?

Rothberg: This is really about creating a personalized medicine. Our sequencers are for research use only now, but eventually we see them being placed in all labs and in any clinical setting. That means doctors will be able to use genetic information to make decisions, such as selecting medicines.

Since it is a 10th the cost of other technologies and 10 times as fast, it will be an ideal fit for medical settings, such as clinical genetics labs and pathology labs. And it works in a time frame of hours, which matches the decision-making time frame that physicians often have.

Where do you think the technology will be adopted first?

We are already seeing it put into use for cancer and infectious disease. Researchers at Massachusetts General Hospital are setting up a system to look at 200 hot spots [regions of DNA that have been linked to cancer] in tumor samples, which could be used to determine potential treatments and to predict outcomes.

People have been talking about incorporating genetic testing into medicine for years, ever since the Human Genome Project. What's different now?

This is absolutely the turning point. Patients will be just as likely to have their genomes sequenced as they will be to get MRIs or CT scans. And sequencing doesn't just tell you where you are; it can tell you the future. You can see whether you are predisposed to disease.

How does it work?

Our chip is laid out like an imaging chip in a digital camera, with millions of sensors that directly detect changes in chemical signals. Over each sensor, we fabricate a little well. Each one of those wells is an independent sequencing machine. One piece of the DNA of interest goes into each one of those wells. Every time a base [or DNA letter] is incorporated into the growing strand of DNA, it releases a hydrogen atom, which the sensors detect. It's kind of like the world's smallest pH meter.

Other machines on the market can analyze more DNA than yours. Isn't that a problem for Ion Torrent?

When you look at our personal genome machine, you are looking at the equivalent of the first video game. Think about what Pong looked like, and then think about what Xbox looks like. In the next few years, you are going to see this transformation [in sequencing].

Right now, we can fit 40 machines [meaning the individual sensors that detect DNA letters] on a human hair. If we make chips in a new foundry, rather than the foundry we are using now, we can fit 4,000 machines on a hair. And we can go even denser. Memory chips have billions of cells, and there is nothing stopping us from doing the same. We plan to make sensors that can directly detect billions of simultaneous sequencing reactions.

You haven't yet sequenced a complete human genome—does that matter?

We found out that 80 percent of labs today want to sequence sets of genes, from one to 500 genes—not exomes [the portion of the genome that corresponds to genes] or genomes. The first chip is designed for that market. The diagnostic samples are huge opportunities. [Clinical labs] do 25,000 to 100,000 samples in which they want to sequence 10 to 500 genes. For HIV, you sequence [particular] viral genes a million times to see if the virus has grown resistant to certain drugs.

You have founded a number of sequencing and genomics companies. What was your guiding principle for Ion Torrent?

We took the same approach as the computer guys. Rather than a large, expensive instrument that is hard to build, ship, and set up we aimed [for something more like] a personal computer that anyone could set up and use.

Photograph by STEVE MOORS


ion torrent

PHOTO ESSAY

British Sea Power

Tens of kilometers from shore, the wind blows faster and more steadily than it does on land. But offshore wind farms are expensive and complicated to build and maintain. The Danish company Dong Energy is constructing what will be one of the world's largest such farms, a 367.2-megawatt, $1.5 billion project off the coast of England using Siemens wind turbines as tall as a 30-story building.

By KEVIN BULLIS

PAUL McMULLIN

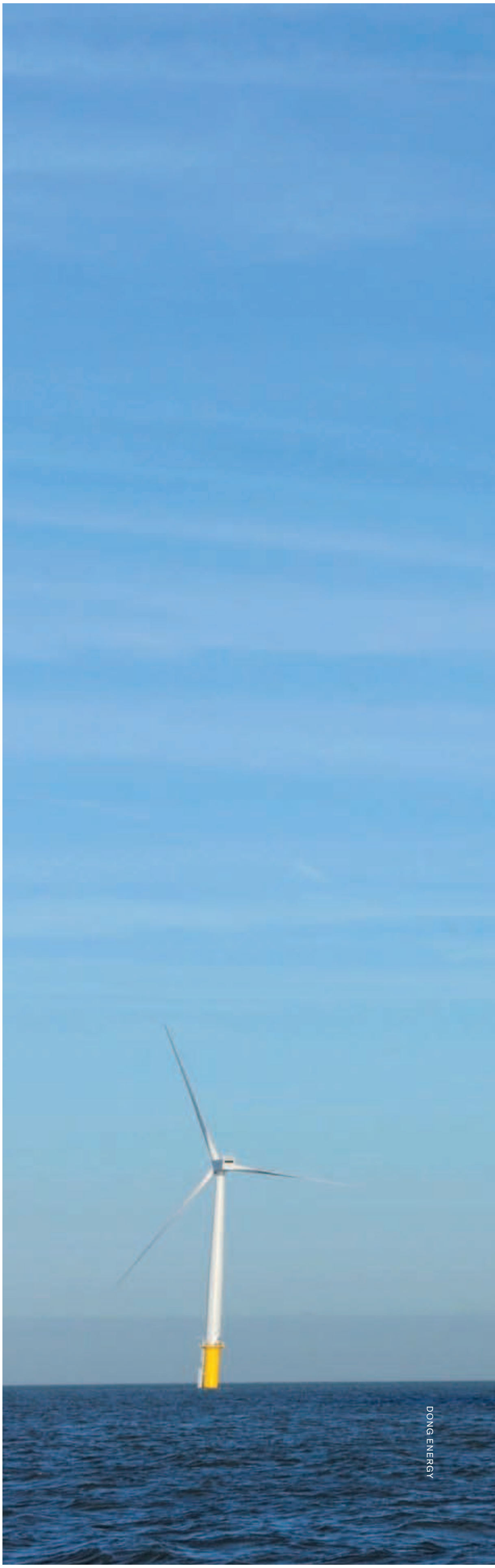
Under threatening skies, ships lay power cables between the 150-meter-high turbines and an offshore substation (left), where the voltage of the current they generate is increased before it's transmitted the 45 kilometers to shore. The turbines can produce 3.6 megawatts each, twice as much as those commonly used on land.

It takes 24 hours to load the components of a pair of wind turbines onto the ship that will take them on the eight-hour trip to the wind farm. This trip will be repeated 51 times to complete the facility. The tall cylinders in the image at right will support the generator housing that's being hoisted onto a waiting ship.

Both loading and installing the 440-ton wind turbines require each component to be placed precisely. This makes it necessary to use a ship that can be jacked up from the ocean floor for stabilization.

In the image below, a worker inspects the bolts at the end of a wind turbine's blade. They will be used to attach the blade to the turbine hub (bottom of page) once the components reach their destination, in the Irish Sea.

PAUL McMULLIN

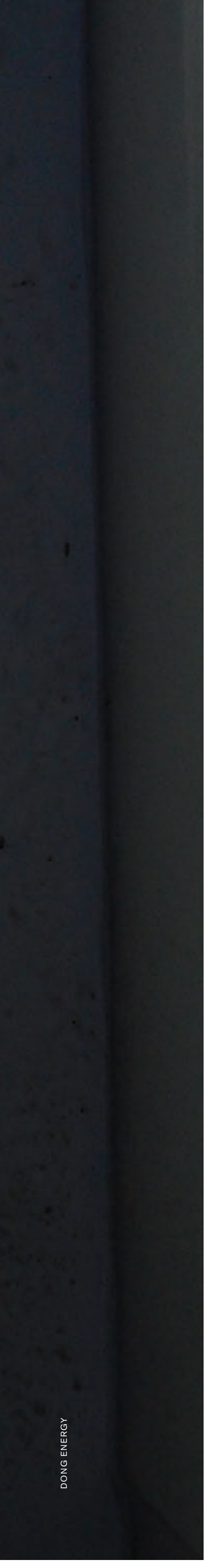


DONG ENERGY

The weather conditions that make the Irish Sea a promising location for a wind farm also make construction a challenge. The turbines are designed to operate at average wind speeds of over four meters per second, reaching full power generation at 14 meters per second. Installation, however, can be undertaken only in calm weather: winds swifter than 10 meters per second can shut down operations. At top, a ship approaches a yellow tower mounted on a 56-meter structural pile that has been hammered into the sea floor. Once the ship is jacked up (above), the two tower pieces and the generator housing, called the nacelle, are installed with the help of a crane. Finally, the blades are hoisted into place (right).


PETER SILLS/DONG ENERGY

DONG ENERGY



DONG ENERGY

Installing the transmission lines that deliver power from the wind turbines to land requires a massive plow (right) to bury electrical cables two meters under the sea floor.

Bad weather can stall construction and prevent repair work on completed turbines, forcing them to sit idle until the sea calms enough for workers to climb to the top of the tower. The photo at left shows the view from such a precarious perch. To prevent construction delays, however, Dong Energy is testing technology that will allow ships to continue working in relatively high waves. A gangway between a ship and turbine tower (above) is connected to a system that enables it to move to compensate for the waves, giving workers stable access.

Robotics: from Surgery to Scouting

A surgeon scrutinizes a three-dimensional real-time representation of her patient's knee on a video screen. She decides which diseased areas need to be excised, and exactly where the robotic arm should be positioned to remove tissue and resurface the knee. Then she manipulates the arm to carry out the surgery, with significantly greater precision than any surgeon would be able to accomplish on her own.

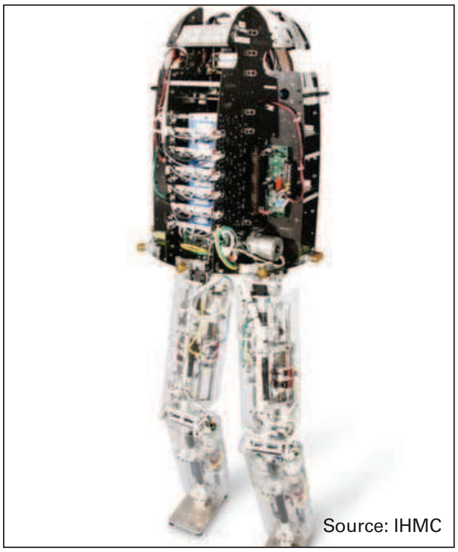
This robotic knee surgery is the brainchild of Mako Surgical Corporation, a Ft. Lauderdale, FL-based medical device company. It's one of many advances in robotics that companies and research institutions in Florida are making in areas that include the life sciences and defense industries.

Many industries, including makers of pharmaceuticals and medical devices, now utilize robots. According to the Robotics Industries Association, the use of industrial robotics grew rapidly in 2010, particularly in the life sciences, where it jumped 54 percent. The expansion is presenting opportunities for manufacturers, technology companies, and research institutions.

Automated Drug Research

Robotic machines are revolutionizing biology research, says Layton Smith, director of drug discovery at Sanford-Burnham Medical Research Institute in Orlando, FL. Industrial robots reached maturity just as researchers were delving into genomics and related fields. The Sanford-Burnham robot's yellow arm can manipulate tiny test tubes, as many as 1,536 to a plate, and move them rapidly through screening processes.

"Our robot automates experiments and can screen anywhere from a hundred thousand to even up to a million compounds in 24 hours," says Peter Hodder, a scientific director of the Translational Research



Source: IHMC

Institute at Scripps Florida. Scripps and Sanford-Burnham own two of only four such NIH-funded robotic screening platforms in the country.

Both labs have recently seen successes thanks to robotic assistance. Smith's lab at Sanford-Burnham has teased out the role of a particular protein in heart disease, a protein he considers a potential target for drug therapy. And Scripps is the first center in the country to have developed a compound using this screening technique that is in clinical trials for treatment of multiple sclerosis. Both advances offer the potential for future spinoffs to commercialize the research.

Standing Up for the Military

An unforeseen obstacle on the floor could send a two-legged robot toppling over. Unlike humans, robots cannot feel the forces the terrain underfoot exerts on their joints and limbs and make the corrections to stay upright. This phenomenon is of particular interest to the military, which sees potential in robot scouts and robot-assisted rescue and is funding research at Florida institutions to solve such challenges.

To solve the toppling problem, the robotics group at the Florida Institute for Human and Machine Cognition, a university-affiliated research institute based in Pensacola and Ocala, FL, is focusing on force control and push recovery. According to Ken Ford, IHMC founder and CEO, researchers have developed a bipedal robot that can stand on one leg and thrust its other leg out to steady itself when pushed. They're now working on applying the same techniques to the robot so that it can recover from a stumble while walking.

Greener Ship Scrubbing

Every few years, huge military or cruise ships undergo overhauls of their external coatings of paint and anti-corrosive and anti-fouling agents. Traditionally this is done by sandblasting, which is both labor intensive and a threat to the health of the workers and the environment, since huge clouds of chemical dust can settle all over the shipyard.

Responding to this challenge, Chariot Robotics, based in Palm City, FL, is selling robots that can scurry over a ship's surface, blasting away at its coatings with ultra-high-pressure jets of water and sucking the fouled water and the coatings back up.

Chariot Robotics' Envirobot can strip a ship ten times faster than human workers with spray guns, with higher precision and a significantly cleaner end result.

Download the *Robotics* white paper to learn more about

- robot-assisted surgery;
- robots and rehabilitation; and
- autonomous vehicles.

The 50 Most Innovative Companies 2011

Our second annual list of the world's most innovative technology companies highlights businesses whose work is changing industries and lives.

50

Inventing new technologies and markets

By BRIAN BERGSTEIN

After years of making financial plans at huge companies like Unilever and Electronic Arts, Mat Fogarty realized that management is often out of touch with what is going on in a business. It isn't entirely the executives' fault: sometimes they don't have enough information. Too many realities about how their companies are doing—things the executives *have* to know to make smart decisions—get bottled up at lower levels of the business. For example, several years ago, employees down the chain at Electronic Arts knew that a certain video game was unlikely to ship on time. But executives continued to promise an overoptimistic release date to the outside world, and then they spent millions in a frantic race to meet the deadline. It was too late: the game came out at least a year later. And even though it proved successful, the delay hurt the company's earnings and its stock price.

PUBLIC COMPANIES

A123 Systems

Why: Lithium-ion batteries make electric cars possible at mass-market prices.
Key innovation: Nanostructured electrodes result in lithium batteries more durable and safer than those in cell phones and laptops.

Amyris

Why: Advanced biofuels could help reduce the use of gasoline and diesel.
Key innovation: Its genetically engineered yeast turns sugars into a building block of diesel fuel, which is usable in the existing transportation infrastructure.

First Solar

Why: New types of photovoltaics are reducing the cost of solar power.
Key innovation: "Thin-film" solar panels based on cadmium telluride, which are cheaper than conventional silicon panels, have made the company one of the world's largest photovoltaic manufacturers.

NEW

Goldwind

Why: Increasing the time that turbines are operational will lower the cost of wind power.
Key innovation: Co-developed a direct-drive wind turbine that eliminates the need for a gearbox. Having fewer moving parts reduces the chance of costly mechanical failure.

NEW

Siemens

Why: Improving the electric grid is crucial to making alternative energy sources less expensive.
Key innovation: Developed wind turbines and other technologies for different aspects of the electric grid, from generation to transmission to distribution.

Suntech

Why: Extremely large-scale production of solar panels is reducing the technology's cost.
Key innovation: Developed its own solar cells and equipment for manufacturing them cheaply.

Nissan

Why: Mainstream use of electric cars could benefit the environment, especially where power is produced relatively cleanly.
Key innovation: Nissan's new electric car, the Leaf, has a reasonably modest sticker price of $32,000.

NEW

Toyota

Why: Hybrid cars can significantly reduce gasoline consumption by using an electric motor alongside a gasoline engine.
Key innovation: A market leader with its Prius model, it is developing battery technologies that are helping to make these cars less expensive and more energy-efficient.

Apple

Why: The rest of the consumer electronics industry is scrambling to catch up to the iPad. The iPhone still sets the standard for smart phones, even if its market share slips.
Key innovation: Its limited lineup of mobile devices all run on the same easy-to-use software.

NEW

ARM Holdings

Why: It is redesigning smart phones and tablets so that they'll use much less power and need recharging less often.
Key innovation: Developed energy-efficient customizable chips for mobile devices.

In 2007, Fogarty left EA to found a company that could tap the expertise and insights collectively held by rank-and-file employees. Before long he had a software application that lets businesses set up a "prediction market." It asks employees to bet, in play money, on what they think will happen. "When will this product really be ready to ship?" they might be asked, or "How many units will we sell?" The aggregation of responses can produce remarkably accurate answers and improve the way companies operate. His first customer was Electronic Arts.

Fogarty's company, Crowdcast, is a newcomer on the second annual TR50, our list of the world's most innovative technology companies. We look for companies that are setting the agenda in an increasingly important market, on the verge of disrupting an established market, or creating an entirely new market. What does it mean to set the agenda? It doesn't necessarily equate to having the biggest market share, or else Intel and Microsoft would be in the TR50. Instead, we look for companies whose ideas and technologies are being imitated by other companies.

Energy

Transportation

Computing and communications

Web and digital media

Materials

Biomedicine

Timing plays a huge role in our choices, because technology markets change quickly. Last year we picked Athenahealth for its online health records system, a technology that was getting a push from government policy and other factors. But different innovations in biomedicine now appear ready to have more impact. For instance, researchers have made impressive progress in developing treatments using stem cells. That's why we've added two stem-cell companies, Geron and Cellular Dynamics International, to the list. Another new TR50 company in the right place at the right time is BrightSource Energy, a provider of solar thermal power. The technology uses large arrays of mirrors to focus sunlight on a tower, generating heat that is used to produce electricity. BrightSource is taking advantage of federal funding for alternative energy (including a $1.4 billion loan guarantee) and state mandates requiring California utilities to use more green power. It's building what will be, at least for a time, the world's largest solar plant, a 392-megawatt facility in the Mojave Desert.

Some companies have fallen off the TR50 because they didn't find an innovative solution to new challenges. Adobe Systems struggled to deal with Apple's refusal to make iPads and iPhones capable of running Adobe's Flash software. Plastic Logic is gone from the TR50 now that its Que e-reader, which promised to be especially lightweight yet durable, has been canceled. When we picked Hulu last year, we said it was at the forefront of putting premium video content on the Web. But that description better fits Netflix now. Hulu, which is majority-owned by the parents of three

HTC

Why: Smart phones that run Android have become an alternative to Apple's mobile devices.
Key innovation: Designed well-crafted devices in partnerships with Google and wireless carriers.

IBM

Why: Computing can transform infrastructure such as electric grids and traffic control systems.
Key innovation: Is drawing on its research expertise and that of software companies it's acquired to develop services for many infrastructure industries and expand the market for information technologies.

iRobot

Why: Robots can save lives by doing jobs too dangerous for people.
Key innovation: Its small, agile robots can detect and dispose of explosive devices for the military.

Akamai

Why: The exponential growth in traffic on the Web is possible because of services that route data intelligently.
Key innovation: Its algorithms optimize online routes for content delivery.

Amazon.com

Why: E-books are finally becoming a large, mainstream market.
Key innovation: Even as it seeded the e-book market with the Kindle, Amazon has made it easy for people to read e-books on other devices, such as the iPad.

Google

Why: It still sets the agenda in Web search, even as it pushes the development of Android for mobile devices.
Key innovation: Its software development process remains relatively fast even as the company has gotten very big.

NEW

Netflix

Why: Inexpensive video on demand, delivered over the Internet, undercuts cable and points the way to a likely future for TV.
Key innovation: Built demand for a streaming video service by including it free with DVD-by-mail subscriptions.

American Superconductor

Why: Smart electrical grids and more efficient power lines can help save money and energy.
Key innovation: Its transmission and distribution lines use superconducting wires that can carry up to 10 times as much electricity as conventional copper wires.

Applied Materials

Why: Powerful computing devices are proliferating because of chips that incorporate ever-smaller features without rising in price.
Key innovation: Its machines can make chips that have both vertical and horizontal connections, to pack in more computing power.

Complete Genomics

Why: Many doctors and researchers lack the resources to sequence genomes and analyze them themselves.
Key innovation: Sells sequencing as a service, analyzing DNA samples that customers send in.

NEW

Geron

Why: Embryonic stem cells provide a potential source of replacement tissue for use in treating an array of degenerative diseases and injuries.
Key innovation: Has begun clinical trials for a spinal-cord therapy derived from these cells.

NEW

Life Technologies

Why: Quick, cheap DNA sequencing will lead to new diagnostic tests and targeted treatments.
Key innovation: Its desktop gene-sequencing machine costs $50,000, about a 10th as much as other machines.

NEW

Novartis

Why: Understanding molecular pathways of rare diseases can shed light on common ones.
Key innovation: Introduced the first medication for patients with benign brain tumors associated with a particular genetic disorder; now the drug is approved for treatment of kidney cancer and is in testing for other types.

Pacific Biosciences

Why: DNA sequencing provides a way to detect microbes in the environment and monitor the spread of viruses in our bodies.
Key innovation: Its sequencing machine can read single strands of DNA in real time.

NEW

Roche

Why: Drugs that target genetic mutations unique to cancer cells may be more effective than ones that act more broadly.
Key innovation: A new drug blocks the effects of a mutation thought to be present in as many as 8 percent of all cancers.

PRIVATE COMPANIES

NEW

BrightSource Energy

Why: It efficiently produces solar thermal power, which focuses sunlight to heat water into steam.
Key innovation: A boiler is heated directly with sunlight that bounces off mirrors.

eSolar

Why: Reducing the cost of constructing solar thermal plants will make them more competitive with fossil-fuel plants.
Key innovation: Software controls the mirrors that focus rays from the sun, eliminating the need to position them by hand.

Joule Unlimited

Why: Biofuels could be far cheaper if they weren't made from corn, sugarcane, and other forms of biomass.
Key innovation: Designed microbes that convert carbon dioxide and water directly into fuels.

NEW

Silver Spring Networks

Why: Computer intelligence in the electric grid will make energy distribution more efficient.
Key innovation: Developed hardware and software that standardize the way disparate parts of the grid communicate.

Synthetic Genomics

Why: Genetically engineered microbes are a promising way to make biofuels.
Key innovation: Created synthetic bacterial cells, possibly paving the way for organisms specifically tailored to make fuels.

of the big four U.S. broadcast TV networks, has some advantages, including the ability to let people stream shows even before their season is over. But it also has stopped offering everything for free and tried to sell a subscription package. Meanwhile, Netflix has cleverly woven streaming TV shows and movies into its existing DVD subscription services.

Other companies are joining the TR50 because their technologies are opening new markets. As gene-sequencing technology evolves, for example, the price of analyzing DNA is plummeting, and several companies have machines for sale. Last year Life Technologies bought Ion Torrent, whose founder, Jonathan Rothberg *(see Q&A, p. 24)*, has chosen to make a sequencing machine that is much cheaper—albeit less powerful for now—than his competitors', which are sold mostly to research labs. Rothberg wants to create a market for gene testing in doctors' offices and other clinical settings. By quickly analyzing certain segments of a cancer patient's DNA, for instance, a doctor could better assess potential treatments. Another physician could get fast insights by putting a sample of blood through a machine offered by Claros Diagnostics, another addition to the TR50. With Claros's microfluidic technology, a liquid is pushed through tiny channels on a chip that can analyze such anomalies as the elevated protein levels that can be a sign of prostate cancer.

Selecting the TR50 isn't simple, but some companies are easy picks because their technologies jump out as fresh ways of doing things. Lyric Semiconductor has redesigned the microprocessor so computers can better deal with probabilities; such an approach could make fraud detection faster and recommendation software smarter. Or check out the "augmented reality" software from a Dutch company called Layar: it fills the screens of mobile phones with information about the user's real-world surroundings. PrimeSense, based in Israel, developed technology that lets people play video games without a controller. It uses an infrared projector and camera and a special chip to detect movement in three dimensions, so players can manipulate the on-screen action with gestures and body movements. It's available in Microsoft's Kinect unit for the Xbox 360, but PrimeSense's technology could also be used to control TVs and computers. That makes it a breakthrough with wide potential applications—a great definition of innovation. tr

BRIAN BERGSTEIN IS DEPUTY EDITOR OF *TECHNOLOGY REVIEW.*

ON THE WEB

Visit **www.technologyreview.com/tr50** to see continually updated profiles of the TR50 companies. Each profile explains a company's technology, markets, and strategy in detail. For public companies, we display financial information and market performance. For private companies, we show the latest information on management, investments, and recent deals.

1366 Technologies

Why: Conventional solar power is still too expensive to compete with fossil fuels, in part because of the cost of manufacturing silicon-based solar cells.
Key innovation: Developed a cheaper method for making silicon wafers, the most expensive component of a solar module.

NEW

SpaceX

Why: Budget cuts will force NASA to rely on private companies for supply missions and other tasks.
Key innovation: Introduced a low-cost production method for everything from rocket engines to astronaut capsules.

NEW

Calxeda

Why: Its technology can reduce the cost of computing in data centers.
Key innovation: Runs servers with cell-phone chips rather than processors built on industry-standard designs, which are more power-hungry.

NEW

Lyric Semiconductor

Why: Computer chips that operate with probabilities instead of binary logic could speed applications such as fraud analysis and machine vision.
Key innovation: Its microprocessor uses electronic signals to represent probabilities rather than binary *0*s and *1*s.

NEW

PrimeSense

Why: User interfaces based on gesture recognition make possible new applications in gaming and everyday computing.
Key innovation: Developed the 3-D sensor system that Microsoft's Kinect device uses to track movement.

NEW

Square

Why: Expanding the use of mobile payments will help small businesses.
Key innovation: Built technology that lets anyone accept credit cards using smart phones.

NEW

Cotendo

Why: Web applications must get faster and feel much more responsive to users if cloud computing is to keep growing.
Key innovation: Its technology efficiently routes traffic across the Internet and makes websites faster.

NEW

Crowdcast

Why: Corporate decision-making gets smarter if it taps the insights of rank-and-file employees.
Key innovation: Private prediction markets let employees forecast the results of corporate choices.

NEW

Facebook

Why: Social networking on the Web is becoming a powerful advertising medium and a platform for startups that offer add-on services.
Key innovation: Adapts quickly to shape its site into a medium that advertisers consistently want to use.

NEW

Groupon

Why: By encouraging millions of people to sign up for quirky daily advertising e-mails, Groupon has created one of the fastest-growing revenue generators on the Web.
Key innovation: Offers local businesses a way to guarantee a return on their promotional budget, thereby tapping into a huge advertising pool that has eluded many Web companies.

NEW

Layar

Why: Augmented reality enhances the value of a mobile device, employing its camera and GPS and displaying information about the user's surroundings.
Key innovation: Its development platform lets businesses and advertisers add AR functions to their own apps.

Twitter

Why: Now that the company has begun to make money from its large user base, a service that has woven its way into everyday life is more likely to stick around.
Key innovation: Its business model offers selected opportunities for advertisers while drawing income from deals that let search engines index its content.

Ushahidi

Why: Web tools can help people respond to crises such as earthquakes and political protests.
Key innovation: Its open-source crowdsourcing tool overlays field reports on maps, providing critical and often life-saving data during emergencies.

Zynga

Why: Companies are building businesses inside platforms like Facebook.
Key innovation: Its social games offer people a new way to interact online.

NEW

Lattice Power

Why: Light-emitting diodes are an energy-efficient option for lighting in buildings and homes, but they are still expensive.
Key innovation: Its low-cost process produces LEDs on the same equipment used to make semiconductors.

Novomer

Why: Biodegradable plastics that aren't made from petroleum offer several environmental benefits.
Key innovation: Its polymer-manufacturing processes use carbon dioxide to make plastics needed for packaging.

Serious Materials

Why: Retrofitting existing buildings is a cost-effective way to increase energy efficiency.
Key innovation: Mass-produces windows with energy-saving features such as coatings and gas insulating layers.

Bind Biosciences

Why: Targeting cancer drugs narrowly to tumor cells will reduce the side effects of chemotherapy.
Key innovation: Its delivery system uses peptides to deliver drugs to specific cells.

NEW

Cellular Dynamics International

Why: Screening drugs on human heart cells will help researchers find treatments for cardiac problems and test drugs for toxic side effects.
Key innovation: Uses induced pluripotent stem cells to make large numbers of heart cells for testing.

NEW

Claros Diagnostics

Why: Simple, fast diagnostic tests can help physicians track disease-related markers.
Key innovation: Its microfluidic device for doctors' offices can quickly detect elevated protein levels associated with prostate cancer.

The New Money

Square, founded by the creator of Twitter, lets people accept credit cards with their smart phones. That innovation could transform transactions in surprising ways.

By JASON PONTIN

In Silicon Valley, every serious startup has a founders' story.

In Christmas of 2008, Jack Dorsey, the creator and chairman of Twitter, was visiting his parents in St. Louis. At the time, he was at loose ends. Twitter had five million users, but in October he had been replaced as chief executive by his better-known cofounder Evan Williams, who, rich from the sale of an earlier company to Google, had funded the original development of the communications network. Dorsey was wondering what he should do next. He felt it should be something big and complex. The economy was in a recession, but that was the best time to begin a new venture, he believed. "Everything has been cleared away and you can start fresh," he explains.

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In St. Louis, Dorsey came across Jim McKelvey, a serial entrepreneur he knew. "Jim was my first technology boss," says Dorsey, who at 15 had written CD-ROM software for McKelvey. "We'd not spoken in years, and I had to tell him what Twitter was, but we immediately decided that we wanted to work together again. We didn't know what. But we spoke every week. One day in February he called me and said, 'I've just lost a $3,000 sale because I couldn't accept credit cards.'"

McKelvey himself was in semiretirement from technology: he had become a glassblower. "I was trying to sell a lady from Panama a glass faucet," he recalls, "and I couldn't process American Express from my studio. I was talking to Jack that afternoon on my cell phone, and I was struck by the irony of the fact that I was holding in my hand most of the hardware I needed to complete the sale."

"There we were," Dorsey adds, "with these general-purpose computers pressed to our ears, because we were both iPhone users, and I began wondering, 'Why couldn't he make that sale?' And the next time Jim came into San Francisco, we sat down with a programmer and said, 'We want to figure out how to process credit cards.'"

It took a month to create a prototype. Dorsey concedes, "I had no idea how to start." In fact, an iPhone doesn't have *all* the hardware necessary to accept credit card payments; McKelvey had to build a magnetic reader through which cards could be swiped. Dorsey wrote the software for the server that would process the payments; Tristan O'Tierney wrote the iPhone app.

In March of 2009, the founders demonstrated the system at a small, private conference run by the boutique investment bank Allen and Company. They toured the offices of the credit card companies that would be their most important partners and showed them the prototype. In November, they raised their first $10 million in funding. And on December 1, @jack posted to Twitter: "Announcing our new company, called @Square, which I'm thrilled to be a part of …"

HOW SQUARE WORKS

On a bright winter's day in January, I visited Square's offices, which occupy a floor of what was once the *San Francisco Chronicle* Building. They were new digs. When I complimented an ushering employee on their design, she said that Dorsey cared about such things, and accurately described their décor as "Apple meets *Mad Men*." There were long rows of white benches with large Mac monitors, surrounded by glass conference rooms with modernist

Photographs by TOBY BURDITT

SQUARE UP
Cofounders Jack Dorsey and Jim McKelvey pay for ice cream using Square.

lighting and geometric wallpaper. The floor was polished concrete; the original wooden paneling of the *Chronicle*'s offices had been preserved. Most of the benches were unoccupied: there was room to grow.

In one of the conference rooms, Jack Dorsey, a slight 34-year-old who speaks in quiet, measured tones and smiles seldom (and then only gently), told me he soon discovered that there were good reasons why ordinary people couldn't accept credit cards: the payment system is extraordinarily complex, opaque, and expensive. More, the complexity benefited a number of established interests.

"If I start a coffee store and I want to accept credit cards because no one uses cash or checks anymore, there's this massive friction," Dorsey explained. First, one must apply for a merchant account from a bank or through an independent sales organization (ISO), a middleman that serves smaller merchants. The application requires a credit check, which can take a week. There are startup fees of $35 to $40. One must buy hardware, which can cost as much as $900 for a system that's wireless and mobile. Transaction fees can be to $15 to $25 a month, even if customers don't buy anything.

"So there I am," said Dorsey. "I've got my cash register I bought from Costco for $700 that's basically a calculator with a cash box. And now I've got this other ugly box for taking credit cards. And when someone finally wants a cappuccino, I've got to type into the first box what they're buying, and then type into the second box the number that comes from the first box, and then swipe their card, and then give them a piece of paper to sign and the receipt from the first box, so now they have two receipts—and it just becomes this *mess*."

"And that's just to get started," added Keith Rabois, Square's chief operating officer, who formerly directed business development at PayPal and LinkedIn. "The way the payments industry works is obfuscation. Everyone teases you with low rates like [a] 1.7 percent [charge on transactions], but the real rates are much higher." Accepting payment with a debit card might incur the lowest rate for the merchant; a charge card such as American Express might demand a 2.79 percent fee on transactions; but a credit card, which is asking the merchants to subsidize its rewards program, might charge 4 percent.

Square's innovative payment system eliminates all of this: there's no credit check, no hardware costs, and no fixed costs. For any transaction, Square charges 2.75 percent plus 15 cents, a blended fee from which it repays the card companies and earns its profit. That's it.

Rabois demonstrated his company's product. He plugged a 2.5-centimeter white plastic square into the audio jack of his iPhone, launched an app, tapped a number, and showed me a simple gray screen. (It cost me two bucks to see Square demoed.) I handed Rabois my American Express card; he swiped it through the card reader, also called a "Square." (Invisibly, the reader converted the card's magnetic data into an electrical signal; the app turned that into an encrypted file; and the phone sent the file to Square's back-end servers, which transmitted the transaction through the global payment network.) A second, equally simple screen appeared and prompted me to sign a field with my finger. I was asked whether I preferred a receipt by e-mail or SMS; I chose e-mail, and typed in my address. A final screen told me the transaction was complete. Seconds later, the receipt appeared in my in-box.

That's all it takes to pay someone using Square. Creating an account to accept payment is only a little more complicated. All one has to do is download an app from the Apple App Store or Android Market to an iPhone, iPad, iPod Touch, or Droid device; read the terms of Square's service; type in name, address, telephone number, and Social Security number; and answer a series of personal questions that verify identity. Two days later, a free Square arrives in the mail, but even before then, one can take payment by manually typing in a credit card's number, expiration date, and security code and the card holder's zip code. An e-mail asks for bank routing and account numbers to be posted to a secure Web page.

All this feels surprisingly satisfying. Square is *elegant*. The user's flow through payment or application has been reduced to the fewest possible steps; the app has minimal features. This emphasis comes directly from Dorsey, who says, "I'm really good at simplifying things." He espouses a tremendously attractive belief that good industrial design wins customers' trust by disappearing.

He explains, "People think of design as being visual, but to me it is editorial: 'What can we take away to get to the essence of what we're trying to do?' What I love about a really well-designed product is that you don't think about it. Steve Jobs is a great editor: when you use an Apple phone, its form fades away and all you think about is the content. I want a similar thing for Twitter. With Square, we're trying to accept payments. We have two groups we need to address: our users—the merchants—and *their* users, consumers. We want the merchant to be focused on taking a payment. And for the consumer, for *me*, I want to be able to walk into a coffee store, enjoy my coffee, and walk out and eventually question whether I had paid or not."

Dorsey talks about ubiquity. "I think of Square in the same way we thought of Twitter," he elaborates. "We're building a utility."

WHAT SQUARE IS FOR

Square is the child of two trends, one technological and the other social: the proliferation of networked mobile computing devices and the decline of cash in favor of payment cards *(see infographics, p. 44)*.

Plugging a magnetic reader into the audio jack of a modern phone is a smarter way to process card payments. But Square is not really a hardware company. The company assumes that more phones will have card readers built into them; perhaps emerging technologies like near-field communications, which transmits data over short distances, will eliminate readers altogether. Square's little white dongle hardly matters: it just introduces the idea that anyone with a smart phone can now accept credit cards. Square is a software company whose essential innovation is a disruptively simpler process for payments.

Already, Square appeals to a large number of people, who are unusually passionate about what is, after all, a financial service. Fifty thousand people enrolled in a pilot program, which began shortly after Dorsey announced the company on Twitter. From the system's official launch last October through December, 100,000 activated accounts. In January, 65,000 signed up. Rabois says that the company hopes to process $1 billion in transactions in 2011. (It would be a stretch: today, it is processing $2 million to $10 million per week.)

Ayr Muir, the founder of Clover Food Lab, which runs vegetarian trucks and a restaurant in the Boston area, signed up for Square's pilot. "Credit card systems are *awful*," says Muir, who is a graduate of MIT and Harvard Business School and a former McKinsey consultant. "The merchants [the ISOs] are shady: they're not transparent, they don't give you fair rates, and you end up paying much more than you expect to pay. Everything is very expensive. We had iPhones and Touches, so an alternative way to take payments was exciting."

But the system was built to serve a broader group of users than small merchants like Muir who already have some kind of mobile credit card terminal. In fact, it's difficult to delimit the startup's ambitions. Rabois says the company's first likely customers are around 27 million American businesses that cannot accept payment with cards. Additionally, there are 33 million Americans who sell goods and services occasionally, taking payment in person in cash or checks. There are seven million American business owners who, like Muir, already have a credit card terminal but want a better way to process mobile payments. Finally, Square wants to begin offering payment systems outside North America in 2012.

Dorsey talks about ubiquity. "I think of Square in the same way we thought of Twitter," he elaborates. "We're building a utility. Square scales from individual commerce—you're selling a couch on Craigslist, or you're a piano teacher—to small businesses like lawyers or house-call doctors or interior designers, to established retailers like cafés or food trucks."

Its growing list of devoted users, the allure of its potential market, and Dorsey's celebrity have all made Square a sought-after investment in Silicon Valley. In all, the startup has raised $37.5 million from Sequoia Capital, Khosla Ventures, J. P. Morgan Chase, and a long list of celebrated entrepreneurs and angel investors, many of them Dorsey's friends. (There is a common sentiment in the Valley that @jack's replacement by @ev was a grave injustice.) The *Wall Street Journal* reported Square's valuation to be $240 million, a swollen sum for so new a company.

A different kind of endorsement has come in the form of large corporations joining the mobile payment business. VeriFone has launched Payware Mobile, Intuit has launched GoPayment, and TF Payments has launched FocusPay: all allow users to accept credit cards by fixing magnetic card readers to smart phones. These large companies have observed the same general trends that sired Square, and they know that global mobile payments totaled $79 billion in 2010; the sum is expected to grow to almost $119 billion in 2011 *(see infographics)*.

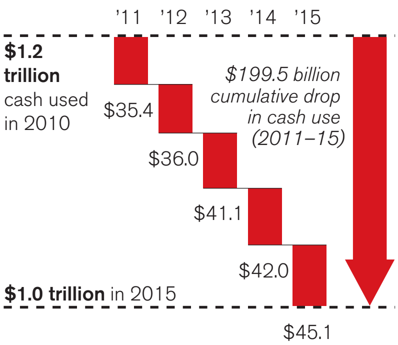
Rabois claims not to worry about outsize competitors. Their hardware may resemble Square's, but they are not offering users a new payment system. Like traditional ISOs, they resell merchant

HOW ARE YOU GOING TO PAY FOR THAT?

Not with cash but with cards and on mobile devices.

Cash is declining in popularity as a form of payment in the United States.

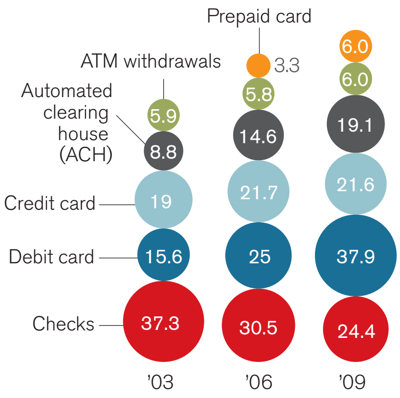
Forecast change in cash use, 2011–2015
(All figures in billions)



Source: Aite Group

Credit card use is growing at the expense of checks.

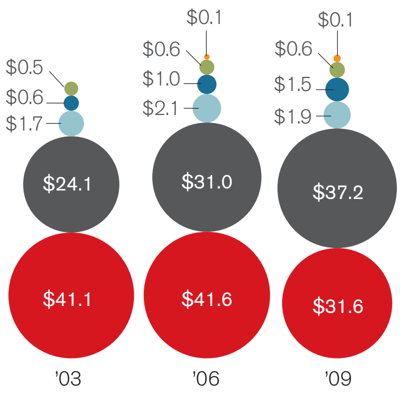
Volume of noncash payments in the U.S., 2003–2009 (billions of transactions)



Source: 2010 Federal Reserve Payments Study

But checks and direct deposit (ACH) still move more money.

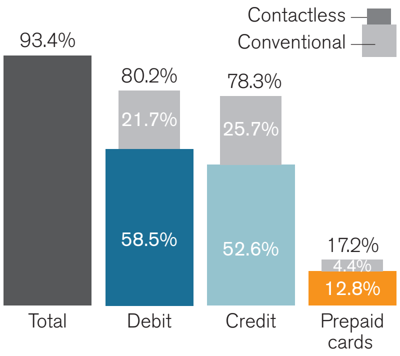
Value of noncash payments in the U.S., 2003–2009 ($ trillions)



Source: 2010 Federal Reserve Payments Study

Debit cards are only slightly more popular than credit cards in the U.S.

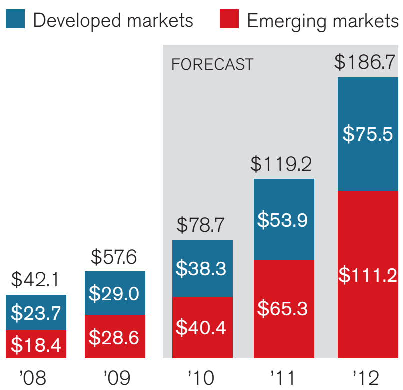
Current adoption of payment cards
(in the U.S.)



Source: 2008–2010 Federal Reserve Bank of Boston Survey of Consumer Payment Choice

Globally, when people pay with cards, they increasingly use a mobile device.

Global mobile payments, 2008–2012
($ billions)



Source: Capgemini, RBS, and EFMA
Euros have been converted to dollars

accounts, and with those accounts come the complexities, opacities, and expenses of the traditional payment systems. "I worry about internal issues like having a zero-defect product," Rabois says.

HOW SQUARE GREW

Rabois *should* worry. Internal issues plagued the launch of Square's service.

People who signed up for the pilot program waited a long time for their Squares. When the readers finally arrived, they were not easy to use. Because the read head was so much smaller than conventional heads, it didn't always capture the card data: people were forced to swipe cards repeatedly. In addition, the original Squares wouldn't work with the iPhone 4's external metal antenna bands. (Ridiculously, users were seen slipping a scrap of paper between the reader and the phone.) There were problems, too, with managing the risk of fraud: to limit its exposure, Square at first imposed a $100 cap on transactions, which severely constrained how the system could be used.

These problems disappointed many early adopters. "I had to swipe two, three, seven times," says Clover's Muir. "It was sort of

TOMMY McCALL

goofy." He applauds the simplicity of what Square is doing, but he adds, "For me, they only need to do a few things, and they need to get those things perfect." Those things involve speed, dependability, and what he calls "price parity." He means that Square's transactions fees should be no more than the rates advertised by ISOs and banks: if he's selling a $5.00 sandwich, a fee of 2.75 percent plus 15 cents is too expensive. (Square would tell Muir that he's paying more than 2.75 percent on many of his transactions but can't see it because the traditional system is so opaque. Dorsey says, "When you ask, most merchants don't know what they're really paying.") Muir concludes, "Payments are a mess, and *someone* is going to solve the problem, but I don't know if it's going to be Square, or Verifone, or someone else." For now, he uses Square as a secondary system if his credit card terminals fail.

Square's executives say they've fixed the initial problems, although they are committed to their blended fee. McKelvey, who until recently was in charge of the company's hardware, increased the size of the reader, and the startup's engineers improved the app's ability to process the signal: today, a card will very often be read with a single swipe. Square abandoned the unpopular $100 cap in transactions and in its place imposed a "threshold": if a user takes in more than $1,000 in one week, the amount over that sum is not paid out immediately but held for 30 days in case the funds must be returned. If a user provides Square with additional information or proves trustworthy over time (another kind of information), the threshold is raised.

Dorsey insists he doesn't mind if Square makes mistakes. "I think we should make lots of mistakes and learn from them," he says. "Mistakes are *great*, so long as the users aren't hurt by them."

WHAT SQUARE COULD BE

McKelvey's glass faucet (a lovely, ridged golden-orange spiral) is now installed behind a bar at the company's headquarters. McKelvey sold it to Dorsey on Square.

There may be great value and even beauty in making simple and transparent a system that was complex and opaque, but that's not what makes Square really interesting. The source of its fascination is that the startup could digitize payments now made with cash or checks and the resulting data could be mined to extract valuable information. "Ninety-four percent of all transactions are now offline," Dorsey told me, shaking his head at the possibilities.

Certainly, that's the real reason Square's investors are so interested. Gideon Yu, who was the chief financial officer of Facebook and treasurer of Yahoo, and who is now a partner at Khosla Ventures, spends one day every week at Square, minding his firm's investment. He says, "Complex problems are necessary but not sufficient to create an opportunity. The information, the analytical benefits, that Square provides are going to be the major driver of value in the future."

No one at Square really knows what "value" the information will provide. The governing assumption is that surprising things will happen as Square becomes broadly adopted, just as they did as Twitter grew. Yu offered this example: "Here's just one, which in itself could be a billion-dollar business—what if we could combine your transaction data, your geodata, your social data, and analyze it to give you a much better, multidimensional idea of your credit score?"

Dorsey provided another: "What's most interesting is the data. Imagine you had Google analytics for your coffee store—not just how many people bought your cappuccinos, but what was your busiest hour and how many also bought biscotti. Online businesses have that data; maybe Starbucks and Peet's have some; but most businesses don't. Businesses need that data to grow. You can make critical decisions with that information. We're the only ones with itemized data of what people are buying and selling."

When asked the difficult, personal question—why Square after Twitter?—Dorsey began to talk about these larger opportunities. "My background is in real-time transactions," he said. (It's true: after dropping out of New York University, he moved to Oakland and wrote dispatch routing software.) "I love low-level stuff. Twitter is about minimizing frictions around communications. But there have been innovations in communications for hundreds of years, and lots of them had really good design. But you can't say the same thing for payments. When I think of the opportunity to design that, to get down to its essence—I don't think anyone has ever done that before." He asked me to try to visualize a real-time map of how people are spending their money: "There's no greater indicator of interest than purchasing something," he said.

I was finished with my interviews. It was the end of work on a Friday. I was invited to stay for the company's weekly "Town Square." Employees pulled chairs into a makeshift theater, opened microbrews, drank wine. At these events Dorsey sometimes rouses the troops. But on this occasion, in keeping with his guiding management philosophy of the chief executive as Zen editor, he didn't say much, happy for his staffers to tell each other about their work. Rabois moderated. He presented the volume and number of transactions processed; the company's graphic designer unveiled a minor refinement of the already austere logo; someone in customer relations explained a new interface for online support.

They were all cool kids: the boys wore Buddy Holly glasses and low-slung jeans and had stubble and tattoos; the girls wore flat shoes and tight jeans and had bangs and tattoos. If it had been Brooklyn, they'd have been affectless artists. But it was San Francisco, so they worked for a technology startup, and I listened as they cheered each presenter, transparently sincere in their enthusiasm for Jack Dorsey's vision of making payments beautiful. tr

JASON PONTIN IS *TECHNOLOGY REVIEW*'S EDITOR IN CHIEF.

Praying for an Energy Miracle

Every clean-tech startup these days claims to have a breakthrough that will finally make renewable and clean energy sources cheap enough to compete with fossil fuels. But are we really on the brink of a clean-energy economy?

By DAVID ROTMAN

The company's breakthrough is strictly off-limits to outsiders. Work on the technology goes on in an unseen part of the sprawling one-story building, beyond the machine shop, the various testing and fabrication instruments, the large open office space stuffed with cubicles. What a visitor gets to see instead is a thin wafer of silicon that would be familiar to anyone in the solar-power industry. And that's exactly the point. The company's advance is all about reducing the expense of manufacturing conventional solar cells.

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In its conference room is a large chart showing the declining cost of electricity produced by solar panels over the last three decades. The slightly bumpy downward-sloping line is approaching a wide horizontal swath labeled "grid parity"—the stage at which electricity made using solar power will be as cheap as power generated from fossil fuels. It is the promised land for renewable power, and the company, 1366 Technologies, believes its improvements in manufacturing techniques can help make it possible for solar power to finally get there.

It's an ambitious target: even though silicon-based photovoltaic cells, which convert sunlight directly to electricity, have been coming down in price for years, they are still too expensive to compete with fossil fuels. As a result, solar power accounts for far less than 1 percent of U.S. electricity production. And 1366 founder Emanuel Sachs, who is the company's chief technology officer and an MIT professor of mechanical engineering, says that even though solar might be "within striking distance" of natural gas, existing solar technology won't be able to compete with coal. "To displace coal will take another level of cost reduction," says Sachs. That's where 1366's breakthrough comes in. The company is developing a way to make thin sheets of silicon without slicing them from solid chunks of the element, a costly chore. "The only way for photovoltaics to compete with coal is with technologies like ours," he says.

Once photovoltaics can compete with coal on price, "the world very much changes," says Frank van Mierlo, the company's CEO. "Solar will become a real part of our energy supply. We can then generate a significant part of our energy from the sun."

JORDAN HOLLENDER

SILICON SAVIOR Emanuel Sachs, founder of the solar startup 1366, has invented a cheaper way to turn chunks of silicon into the thin wafers used in photovoltaic cells.

In a number of ways, 1366 (the name refers to the average number of watts of solar energy that hit each square meter of Earth over a year) reflects the ambition of a whole generation of energy startups. These companies often refer to "game-changing" technologies that will redefine the economics of non-fossil-fuel energy sources. Many were founded over the last decade, during a boom in venture capital funding for "clean tech"—not only in solar but also in wind, biofuels, and batteries. Many have benefited from increases in federal support for energy research since President Obama took office. Though the companies are working on different technologies, they share a business strategy: to make clean energy sources cheap enough, without any government subsidies, to compete with fossil fuels. At that point, capitalism will kick into high gear, and investors will rush to build a new energy infrastructure and displace fossil fuels—or so the argument goes.

The problem, however, is that we are probably not just a few breakthroughs away from deploying cheaper, cleaner energy sources on a massive scale. Though few question the value of developing new energy technologies, scaling them up will be so difficult and expensive that many policy experts say such advances alone, without the help of continuing government subsidies and other incentives, will make little impact on our energy mix. Regardless of technological advances, these experts are skeptical that renewables are close to achieving grid parity, or that batteries are close to allowing an electric vehicle to compete with gas-powered cars on price and range.

In the case of renewables, it depends on how you define grid parity and whether you account for the costs of the storage and backup power systems that become necessary with intermittent power sources like solar and wind. If you define grid parity as "delivering electricity whenever you want, in whatever volumes you want," says David Victor, the director of the Laboratory on International Law and Regulation at the University of California, San Diego, then today's new renewables aren't even close. And if new energy technologies are going to scale up enough to make a dent in carbon dioxide emissions, he adds, "that's the definition that matters."

FIELD OF MIRRORS

Few people have more faith in the power of technology to change the world than Bill Gross. And few entrepreneurs are as familiar with the difficulty of turning clever ideas into commercial technology. In the dot-com era, he and his company Idealab, an incubator that creates and runs new businesses, started up several of the era's hottest firms, only to struggle when the bubble burst.

Gross latched onto the clean-tech craze, founding a company called eSolar in 2007 to work on solar thermal technology *(see Q&A, March/April 2010 and at technologyreview.com)*. These days, Web, social-computing, and energy projects are intermingled in Idealab's tightly packed offices in downtown Pasadena, California. In keeping with its dot-com-era heritage, the offices occupy a large loftlike space full of various companies or hope-to-be companies, some of them consisting of no more than a few desks dominated by large computer screens. Somewhere in all the brushed metal, exposed ventilation systems, track lighting, and designer desk chairs is Bill Gross's office, a small glassed-in cubicle.

Like almost every other founder of a renewable-energy startup, Gross gets right to the numbers. Pulling up a screen that compares the costs of energy from various sources, he points out how a technology being developed by eSolar could make solar thermal power less expensive and help it become competitive with fossil fuels. Solar thermal plants produce electricity by using a huge field of mirrors to focus sunlight on a tall central tower, where water is heated to produce steam that generates electricity. Large power plants using the technology can produce electricity more cheaply than ones using silicon solar panels, although the thermal approach is still more expensive than power derived from coal or even wind. Several such plants are operating around the world, and more are being built *(see "Chasing the Sun," July/August 2009 and at technologyreview.com)*. In 2006, when the giant California utility PG&E put out a bid for a 300-megawatt solar thermal plant (now being built by a company called BrightSource), Gross got excited and began working with his employees to improve the economics.

Not surprisingly, Gross's solution is based on software. Large solar thermal plants cost more than a billion dollars to build, and one reason for the high cost is that tens of thousands of specially fabricated mirrors have to be precisely arranged so that they focus the sunlight correctly. But what if you used plain mirrors on a simple metal rack and then used software to calibrate them, adjusting each one to optimize its position relative to the sun and the central tower? It would take huge amounts of computing power to manipulate all the mirrors in a utility-scale power plant, but computing power is cheap—far cheaper than paying engineers and technicians to laboriously position the mirrors by hand. The potential savings are impressive, according to Gross; he says that eSolar can install a field of mirrors for half what it costs in other solar thermal facilities. As a result, he expects to produce electricity for approximately 11 cents per kilowatt-hour, enticingly close to the price of power from a fossil-fuel plant.

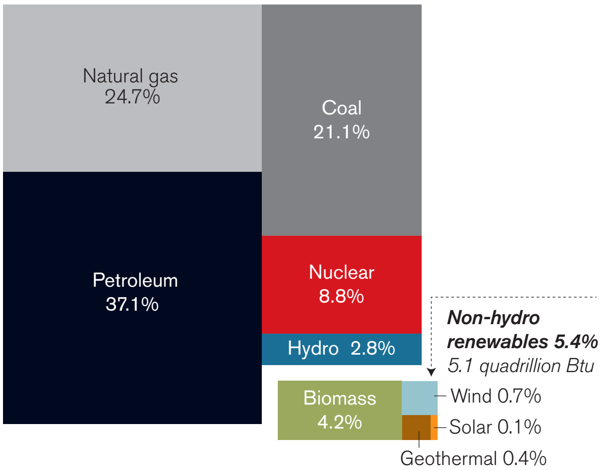
Still, it's not good enough—at least in the United States, where natural-gas plants can produce power for around 6 cents per kilowatt-hour. In Lancaster, California, at the edge of the Mojave Desert, eSolar has built a facility with 24,000 mirrors; it is capable of producing five megawatts of power. But eSolar has gotten no new deals to build utility-scale projects based on the company's technology in the United States. Instead it is doing business in parts of the world where electricity prices are higher or subsidies for renewable energy are greater; it is building a 2.5-megawatt

RENEWABLE CHALLENGE

It will cost billions to scale up and increase the use of energy sources such as solar and wind.

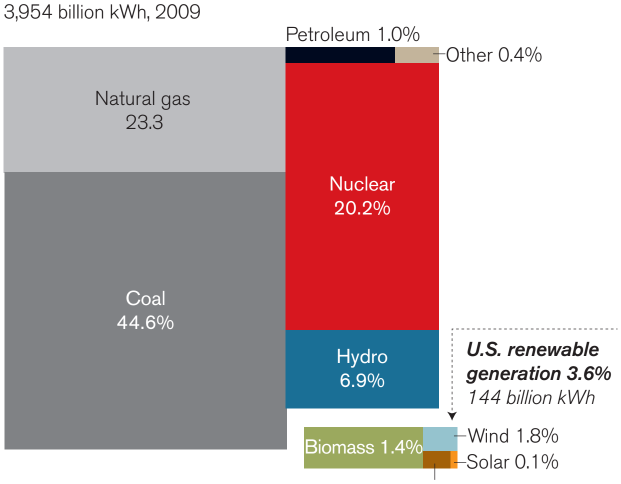
Despite their potential, new types of renewables still account for only about 1 percent of energy use in the United States.

U.S. energy consumption
94.9 quadrillion Btu, 2009



Electricity production is dominated by coal-fired plants, a leading source of carbon dioxide emissions.

U.S. net electricity generation
3,954 billion kWh, 2009



Source: U.S. Department of Energy/NREL

TOMMY McCALL

plant in India and has signed an agreement for a large facility in China. The problem in the United States is the same one facing all alternative-energy dreams: cost. Prices for natural gas have fallen to historically low levels, which means that solar thermal must get even cheaper to compete. To stand a chance in the United States, Gross acknowledges, eSolar needs its electricity to cost no more than 7.5 cents per kilowatt-hour.

Getting there will take yet another advance in the technology. One disadvantage of solar power is that it produces electricity only during part of the day. Photovoltaic panels efficiently produce power for about five and half hours a day, when the sun is most directly overhead. Solar thermal systems can operate a bit longer, because the heated water can drive turbines later into the afternoon; eSolar's technology makes power for about seven hours daily without storage. And Gross says that using molten salts instead of water to transport the heat from the central tower to the steam generator will enable a solar thermal facility to store the heat for much longer and produce electricity for up to 16 hours a day. That will bring down the cost of its electricity to the targeted 7.5 cents per kilowatt-hour. He predicts that eSolar will have a commercial plant with the molten-salt design running next year.

If the goalposts keep moving just beyond the reach of new energy technologies, Gross doesn't seem fazed. Eventually, he says, eSolar's technology won't need subsidies to compete with natural gas, and the sky will be the limit. "Solar is perfect for a huge swath of the planet," he says, happily showing a world map with a large belt around the middle in red and dark orange, indicating high levels of solar radiation. Even in this country, Gross says confidently, solar power will account for half of all electricity production by 2050—with at least 50 percent of that produced by solar thermal plants.

"NO BUGS"

While Bill Gross tries to squeeze a few critical pennies out of the cost of solar power, researchers at Caltech, a few miles up the road, are working on a different solution. They are trying to invent a fundamentally new way of producing liquid fuels directly from sunlight, inspired by the way green plants convert sunlight to sugars. If this quest for "artificial photosynthesis" succeeds, it will address one of solar energy's fundamental challenges: how to store the power until it's needed. The potential of this vision seems to animate the director of the effort, Nate Lewis. He speaks at times in bullet points punctuated by a mix of excitement and impatience. "No bugs, no wires," he says. "No bugs, no wires. I mean what I say: no wires. Leaves have no wires. In come sunlight, water, and CO_2, and out come fuels."

This research—a joint project of Caltech and Lawrence Berkeley National Lab—will be supported by $122 million over five years from the U.S. Department of Energy, pending Congressional appropriation of the funds. "We have pieces. Making fuels from sunlight with photoelectric chemistry works," says Lewis, a professor of chemistry at Caltech. But a practical device needs to be cheap, efficient, and robust. "Right now, I can give you any two of the three at the same time," he says. "Our goal is all three." Basic scientific problems stand in the way. Among them: the researchers need to

find cost-effective catalysts for the chemical reactions that break water into oxygen and hydrogen.

After 100 years of research, "you can count on one hand the classes of compound that are good catalysts for water oxidation," Lewis says; we "don't have another hundred years" to find better ones. Employing the kind of high-throughput experimental methods and automated techniques increasingly used in drug discovery, the center will screen a million compounds a day for catalytic activity. "We will evaluate, discover, and quantify the activity of more catalysts in one day than have been collectively documented throughout history," he says.

Meanwhile, a team of system designers and hardware experts will begin to design and build prototype devices. "Their job is to build prototypes from day one," Lewis says. "We expect to have [the prototypes] within the first two or three years." Those first prototypes will "nearly absolutely fail," he says, but they're the only way to arrive at a practical system: "We don't know what it should look like. Where does the water come out? Where does the sunlight come in? If you don't build the thing, you can't build the thing."

The challenge of finding cheaper and cleaner energy has often been compared to the race to put a man on the moon. But there's at least one key difference: success at getting humans into space was not judged according to its cost. Regardless of how clever Lewis's technology might be, it won't solve the problem unless it can serve as the basis of a sustainable business. "We're not NASA going to the moon," says Lewis. "If you can't compete on cost, it's ultimately not worth doing." And, he adds, given the fluctuating price of oil, you've "got to have something that looks like it is really disruptive" in terms of cost: "If you're just close, it's no good for anyone."

WORLD OF AUSTERITY

In the last decade, many U.S. energy experts and economists have argued that the government must establish a price for emitting carbon dioxide. They say that a carbon price—in the form of either a tax or a cap-and-trade system—would be an economically efficient and technologically fair way to reduce our use of fossil fuels. It would drive up the cost of energy derived from those fuels, allowing cleaner technologies to challenge them in the market without requiring the government to back particular choices. The European Union implemented a cap-and-trade system in 2005, but the United States—until recently the world's largest user of energy and, arguably, still the leading center of energy innovation—has failed to do so.

That has left energy policy experts debating how to go forward—especially now that subsidies and other benefits for clean energy in the 2009 federal stimulus bill are winding down. Some see an opportunity to focus on inventing new ways to make clean energy cheaper than fossil fuels. Such innovation, they contend, is the only way to achieve massive reductions in fossil-fuel use. Microsoft founder Bill Gates is one of the investors who hope to stimulate such energy "miracles" *(see Q&A, September/October 2010 and at technologyreview.com)*.

Critics of that view, however, believe it's more important to focus on increasing the use of clean energy technologies as soon as possible through government subsidies and other incentives. It's dangerous to believe that "all these amazing technologies will come along and solve the problem," says Joseph Romm, a senior fellow at the Center for American Progress, a Washington-based think tank. The truth is, he says, breakthroughs "don't happen very often."

SOLAR MIRAGE? An eSolar demonstration facility in Lancaster, California, uses 24,000 mirrors and can produce five megawatts of electricity. But eSolar has no U.S. deals for similar plants.

MISHA GRAVENOR

In fact, most technologies get better and cheaper as they are commercialized and used, not in the lab. That means we need both research into new energy technologies *and* government policies that support deployment, use, and improvement. There's an intimate connection between these efforts. "Until you start deployment, you don't know the challenges," says Romm. "So many great ideas happen in the lab but don't succeed in the market. It is the back-and-forth between deployment and R&D that gets you rapid innovation."

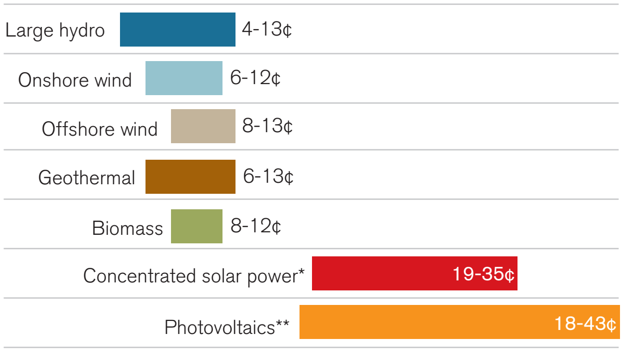
One of the most successful of the recent energy startups is A123, a battery company based in Watertown, Massachusetts. A123, which had a public offering of its stock in 2009, makes lithium-ion batteries that are designed to be safer and longer lasting than the more conventional versions; its secret is electrodes made of nanoscale composite materials. Remarkably, the company went from lab tests of its technology to commercial production in less than three years. It has benefited from strong demand from carmakers desperate to introduce electric vehicles and from a gov-

PRICEY POWER

Different types of solar power remain more expensive even than other renewables.

Concentrated solar power and photovoltaics have gotten cheaper recently but are still relatively expensive.

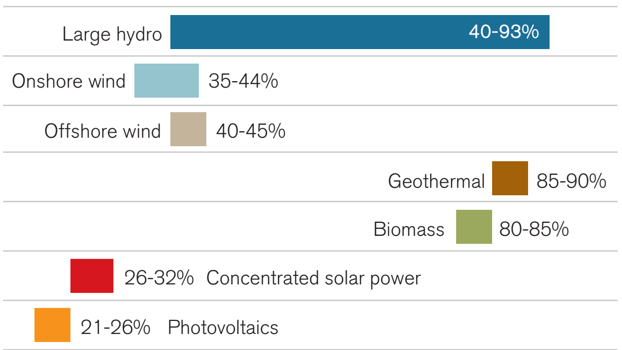
Levelized cost of renewable electricity
Cost per kWh, 2009



*Notes: *Incudes solar thermal and focusing mirrors on photovoltaic cells.*
***Current range of utility-scale photovoltaic installations in the U.S.*

Solar plants produce electricity only during part of the day, limiting their ability to utilize their capacity.

Capacity factor for renewable resources
% capacity ranges, 2009



Source: U.S. Department of Energy/NREL

ernment grant of $250 million to help fund construction of its manufacturing facilities *(see Demo, p. 80)*.

But three years ago, even as A123 was still moving to commercialize its products, cofounder Yet-Ming Chiang, an MIT materials scientist, was already looking for his next breakthrough. Working initially at A123 and later with colleagues at MIT and Rutgers University, he set out to invent a technology that would be far cheaper and easier to manufacture than existing lithium batteries. He wanted a battery that would allow electric cars to drive much farther on a charge, and one that would offer a practical way to store power on the electric grid. The solution: a completely new type of battery, again based on nanomaterials.

Last year A123 spun off 24M, a startup that will test and, possibly, commercialize the technology. The company wants to meet the Department of Energy's goal of developing electric-vehicle batteries that can supply energy for around $250 per kilowatt-hour, as opposed to today's standard of around $500 to $600. The result would halve the cost of a battery for an all-electric vehicle. It would, Chiang says, "enable the widespread adoption of electric vehicles."

Even if Chiang's newest battery creation proves impractical, its invention and the founding of 24M illustrate the benefits that come from the commercialization of energy technologies and the iterative nature of innovation. A123's batteries helped establish a market in which newer advances can compete, and they clarified the limits of the first-generation technology. None of that would have happened without federal support. Government policy is "absolutely critical," Chiang says, both to researching new battery technologies and to scaling up existing ones.

Although some alternative energy technologies might eventually achieve grid parity, few, if any, can survive without subsidies now, as they improve their cost and efficiency. Even with subsidies, including tax incentives and cash grants, most are struggling to narrow the cost gap with fossil fuels. As Caltech's Lewis says, getting close is not good enough. The danger is that if we focus on energy "miracles" and exaggerate the potential of breakthrough technologies, the need for a coherent government policy in favor of energy change will be forgotten. "All the darling energy technologies—essentially all the renewables and all the grid-powered electric vehicles—depend on huge subsidies," says David Victor of UC San Diego. "And no one really knows what a world of fiscal austerity will look like for these technologies."

Clean energy options still have a long way to go, especially when it comes to storing electricity, lowering the cost of renewables, and improving the performance and cost of batteries. Companies like 1366 and eSolar are addressing these challenges. But depending on breakthroughs alone to solve our energy problems is unrealistic. Such advances must take place in the larger context of a coördinated effort to deploy these energy sources. That demands international government strategies that support not just research but testing, building, and commercialization.

Deploying energy alternatives will be far more expensive and, in some ways, far more difficult than inventing new ones. Given today's political climate and the lack of a coherent energy policy around the world, it might truly take a miracle. tr

DAVID ROTMAN IS *TECHNOLOGY REVIEW*'S EDITOR.

TOMMY McCALL

The Slow-Motion Internet

Google's growth plans depend in part on whether it can make the entire Web faster.

By ERICA NAONE

The Internet is no longer fast enough for Google.

To see why, try the Chrome netbook. It's a prototype device that exemplifies one of the company's visions for the future: the idea that we can do nearly all our computing online, accessing information anywhere on a whim. This netbook has a pared-down operating system that's essentially a powerful Web browser. It stores almost no files or software. Almost everything you can do on the device requires an Internet connection.

When I got my hands on the Chrome netbook, I understood why Google (one of our TR50 companies; see page 35) finds the idea compelling. I liked the convenience at first—I always had the files I needed, because the machine forced me to store them remotely, "in the cloud." But one day, I waited minutes for my Web word processor to open a file. I couldn't look at the computer's task manager and solve the problem—I just had to stare at a spinning wheel. Another time, my favorite streaming radio station took forever to load. Once it did start playing songs, the connection hiccupped,

Photographs by DANA SMITH

giving the effect of a skipping CD. Before long, I gave up using the netbook and went back to a computer that could work offline.

These types of failures mean the Internet isn't ready to deliver what Google envisions, which is for networked devices to feel as fluid and easy as PCs that do their computing "locally." And it's not just the idea of relying exclusively on the Web that's in jeopardy: even on an everyday computer, it can be slow and frustrating to do anything important in a Web application. Online apps like the free spreadsheet program from Google sometimes feel sluggish—there can be a lag before a number you've entered shows up on your screen. That is a big problem for Google, because its hopes ride on the prospect that we will all live more thoroughly Internet-connected lives. The company looks forward to a day when, instead of depending on software that resides on desktop computers (often sold by Microsoft), we turn to programs that are run remotely (often by Google).

50

Google has used its dominance of Web search to build an extremely profitable advertising business; it had $8.5 billion in net income last year on $29.3 billion in revenue. But the company knows it can't rely on search forever. Perhaps someone else—Microsoft or a startup—will build an even better search engine. Facebook is pursuing its own vision of a Web—one closed off from Google—that revolves around social connections and personal preferences. Or an unexpected threat might arise. Google has launched many products aimed at capturing more of the time people spend online—not only on PCs but also on new types of devices that range from smart phones to Internet-enabled TVs—but none has yielded significant revenue. This is why Eric Schmidt, who plans to step aside as CEO this spring, tried to push the company in new directions. He told employees to think of Google as a company making software for mobile devices, running on an Internet pervasive and fast enough to blend into any daily activity.

But that isn't able to happen just yet. Like the steady drip of a corrosive fluid, repeated encounters with a slow website eat away at a person's willingness to use Web apps. Bill Coughran, a senior vice president of engineering at Google who oversees its "Make the Web Faster" initiative, says the company fears that the growth of online services could hit a wall if the Web is "too slow or too insecure."

Google's solution is brilliant and ambitious: speed up the whole Web—not just the sites Google runs. That means changing many things that aren't even in Google's control—everything from the way websites are built to the fiber that brings the Internet into people's homes. And it may be more than even Google's vast resources and world-class engineers can manage.

THE ANATOMY OF THE WEB

When people use a website, requests for data have to travel from the browser on their computers to the servers that host that site. The servers determine what to send back. The code that describes how to load the page travels back to the browser; it may include instructions to fetch certain items, such as images or video, which require sending even more messages.

Each of these messages involves a complicated, interconnected nest of hardware and software that is often outdated or poorly designed, or at the very least congested. The routes go through various kinds of physical infrastructure, from high-speed lines that make up the backbone of the Internet to the cables, phone wires, and wireless signals that deliver a site to its intended user.

Performance problems can happen anywhere in that process. The servers hosting a site might be slow. The browser might not handle the code efficiently. The code might be hard to process. On top of that, the back-and-forth negotiation of sending information and determining whether it has arrived is governed by protocols designed decades ago. They were not crafted for the level of speed and interactivity required by modern Web applications that are meant to replace software traditionally run on a PC.

People turn out to be sensitive to the slightest delays. An internal study showed Google that introducing a delay of 100 to 400 milliseconds when displaying search results led users to conduct 0.2 to 0.6 percent fewer searches, and the number of searches dropped ever lower as weeks went by. Once normal speed was restored, it took time for people to resume their earlier searching habits.

Browsing Web pages "should be like changing the channel on the TV," says Arvind Jain, a director of engineering at Google and the technical lead for the Make the Web Faster initiative. The project came about two years ago, at the behest of Google cofounder Larry Page (who will replace Schmidt as CEO). There are problems with "every component" of the Web, says Jain, who speaks with a casual hubris that is quintessentially Google. "We realized we have to fix all of them."

THE WEB IN GOOGLE'S IMAGE

To get started, Jain teamed up with a small group, including Richard Rabbat, who serves as product manager for the initiative. Rabbat tends to criticize the Internet in a joking tone. But he is as convinced as Jain that it is unacceptably slow, especially on mobile devices.

Rabbat grew up in Lebanon, where Internet access was limited by war and a poor economy. As an undergraduate, he shared access with many other people through a satellite communication system called a VSAT, or very small aperture terminal. He vividly remembers how much time he spent waiting for pages to load, waiting to get the information he needed.

When their project began, Rabbat and Jain sat down and mapped out things Google could do to help make the Web faster at every level, including the company's own sites. Expectations at the top of the company ran high. Leonidas Kontothanassis, tech lead for Google's office in Cambridge, Massachusetts, recalls with a broad grin that three minutes before the team that works on Google's ad network headed into a goal-setting meeting one day, they got a message on an internal planning site. The team had been looking at ways to make the ad network run twice as fast. The message indicated that Larry Page wanted to see them make it 10 times as fast. "We had brainstormed stuff we could do to make ads faster, but those nice small wins became irrelevant at that moment," Kontothanassis recalls. The team had to change its approach completely, questioning fundamental aspects of the Internet rather than searching for places to tweak.

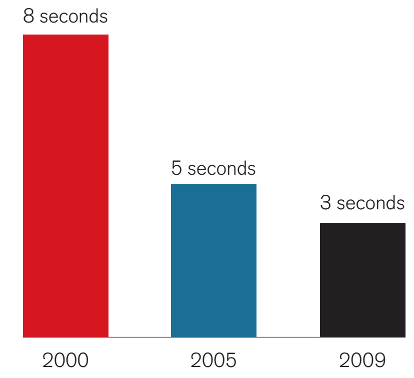
> Like the steady drip of a corrosive fluid, repeated encounters with a slow website eat away at a person's willingness to use Web apps.

Meanwhile, other Google engineers were working on the company's Web browser, which is also called Chrome and came out well before the prototype netbook with the same name. The company designed and built the browser with an eye to the problems that have arisen with the popularity of Web applications. Web apps are programmed largely in JavaScript, through ad hoc techniques that engineers have developed in response to demands for new website capabilities. One of Google's chief innovations for the browser was a new engine for processing JavaScript faster than ever before. The browser's code was opened to the public—among other reasons, in hopes that people would have ideas for making it even faster.

THE NEED FOR SPEED

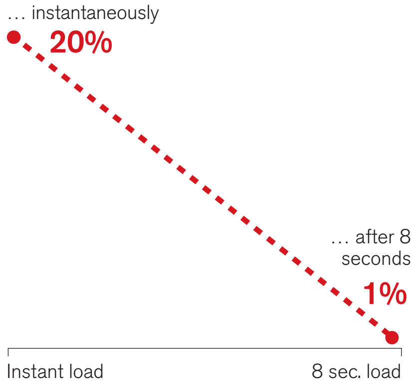
Even slight slowdowns online frustrate people and cost companies money.

How long a person will wait for page to load before navigating away

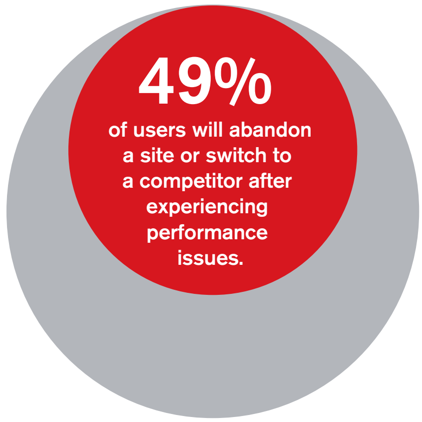


Source: Akamai

Percentage of users who look at a promotion if slide loads*…



*Note: *For slide show taking up 23% of a page. Source: Jakob Nielsen, principal of the Nielsen Norman Group*



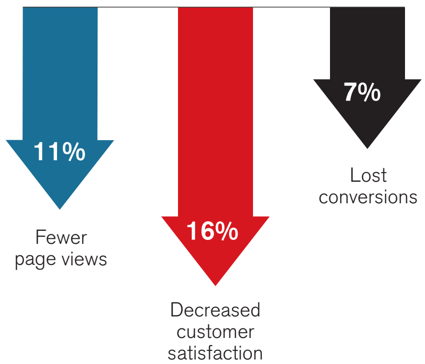
Source: Sean Power, cofounder of the consulting firm Watching Websites

Even a brief delay leads to a lower "conversion rate," which means that a site's visitors take fewer desired actions.

Slow sites get fewer conversions than ones that load in a second, and they have higher "bounce rates"—they lose more users.

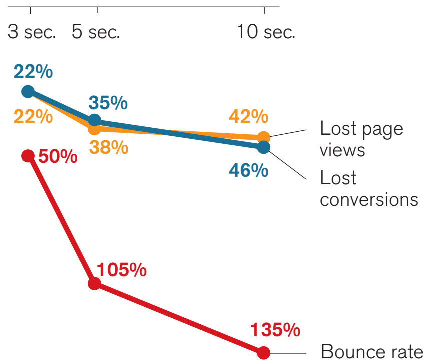
Speed will become an even more important factor for companies as people increasingly access the Web from mobile devices.

Consequences of a one-second delay



Source: Aberdeen Group

Consequences of longer site-load time



Source: Strangeloop

Users who …

Source: Gomez

TOMMY McCALL

Next, because Google's true goal was to improve all browsers, it launched an ad campaign focused on the idea that a faster browser was a better one. Since then, rival browsers Firefox, Safari, Opera, and Internet Explorer have all significantly sped up and given that metric top billing in marketing materials.

If browsers needed to get faster, though, so did websites themselves. In April 2010, Google engaged a powerful weapon to force other sites to improve their performance: it announced that it would begin taking site speed into account when ranking pages in its search engine. As everyone on the Internet knows, if your site is not visible in the first page of Google's search results, you barely exist.

The best solutions of all, Rabbat and Jain realized, would spread with as little human intervention as possible. As Rabbat puts it, "Instead of telling people what the problems are, can we just fix it for them automatically?" Late in 2010, Google released a free tool that website administrators can download. It analyzes sites

and automatically fixes problems that are slowing them down. For example, it changes the way sites handle images in order to make them load more efficiently. The team tested the tool on a representative set of Web pages and found that it typically made a site two to three times faster. Less than three months after its launch, the tool had been installed on more than 30,000 servers.

PUSHING DEEPER

Next the company hopes to reach even further—into the Internet's fundamental architecture. Google has proposed a new protocol, SPDY (pronounced "speedy"), which it says could make Internet communication twice as fast as it is under today's protocols. The current protocols weren't designed for anything near the bandwidth that's available now. The one known as TCP, for example, is set up to make sure no information gets lost. It cautiously increases its transfer rate little by little once a connection is open, testing the water the whole way. If it detects a problem, it cuts its transfer rate in half; as a result, TCP rarely takes advantage of all the bandwidth it has available. Another issue is that many Web pages today are designed so that information loads in sequence—an image here, an ad there, a video there. If all the pieces could be loaded in parallel, the page would reach users much more quickly.

But while everyone agrees that these old protocols slow things down, it won't be easy to replace them. "The challenge isn't so much technical as economic," says Neil Cohen, senior director of product marketing for the content delivery network Akamai. Replacing the old standards would require updating users' operating systems and changing servers, networking hardware, and other equipment all across the world.

In the meantime, Google plans to pressure Internet service providers until they offer connections that meet the standards the company expects and needs. In the coming years, Google will build and run a one-gigabit-per-second Internet connection for a community in the United States, its location yet to be announced. This is 20 times faster than what Verizon Communications generally delivers over its FiOS fiber-optic service—which is one of the fastest consumer plans today—and 100 times faster than what most Americans have. Google hopes that the project will yield technical information about what it takes to provide that level of service, and that it will encourage consumers to demand higher speeds.

But even with higher connection speeds, software would need to be redesigned to take full advantage of the greater capacity. And building the necessary infrastructure would be grueling, expensive, and time-consuming. In 2010, Verizon said it would finish existing FiOS construction projects but launch no new ones; not even its relatively fast service will reach many customers. Google may offer very high speeds to some test communities, but it is unlikely to become an Internet service provider on any significant scale.

Moreover, some of the problems with the way infrastructure is deployed are not within Google's power to resolve. "In many cases, the failure of the system happens at intermediary stages," says Tom Hughes-Croucher, a performance expert at Joyent, a provider of cloud-computing infrastructure. For example, he says, even with an improved protocol like SPDY, an Internet service provider's misconfigured server could slow the Web experience for thousands of people. Slowdowns are common in South America and Africa because they have few local data centers; pretty much all information must travel farther to reach users. "It's a policy thing," Hughes-Croucher says. "It's something for governments to solve."

Finally, even if Google's projects pan out, the company could still be stymied. For one thing, Google's overall market power—which gives it the ability to push other companies into pursuing its goals—has come under fire, particularly in a European Union inquiry into whether Google exerts unfair control over the rankings in its search engine.

Regardless, Google's confidence in its power to change the Web seems boundless.

I asked Rabbat and Jain what will happen if some of Google's speed projects don't succeed. They looked at each other in confusion, and then Rabbat started laughing. "We have not explored the failure scenario," he said. He repeated the sentence a few times.

He collected himself and leaned forward, speaking seriously now. "We believe we can do this," he said. "With the size of Google, people will listen—they will try out options we suggest."

Jain nodded fervently. "That's exactly right. Everyone wants this, not just Google. Everyone understands that this work will benefit everyone. It won't be a Google success. It will be a success in the Internet as a whole." tr

ERICA NAONE IS *TECHNOLOGY REVIEW*'S EDITOR FOR WEB AND SOCIAL MEDIA.

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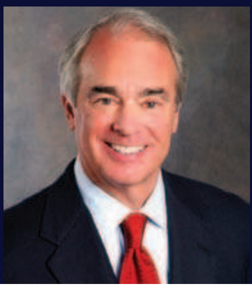
U.S. Secretary of the Navy Ray Mabus will headline the 2011 MIT Energy Conference on March 5. Secretary Mabus leads the charge among high profile decision-makers that are pushing to improve the ways we generate and use energy in the United States military.



Jim Rogers, Chairman, President and CEO of Duke Energy

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- **Valuing Risk in Big Energy -** How does policy risk impact technology development and deployment decisions in large companies? What challenges and opportunities do these risks create for energy start-ups?
- **Strategic Materials for Energy -** Mainstream media frequently discuss the geopolitical importance of global lithium scarcity. What are other scarce materials that are or will become important for our energy future?

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BRIEFING

Private Spaceflight

LIFTOFF Last December's successful test flight of SpaceX's Falcon 9 rocket and Dragon capsule was a critical step toward starting private cargo deliveries to the International Space Station this year.

A new space age beckons—if customers can be found

For decades, national space agencies like NASA held an iron grip on space travel. But in the last few years their budgets have been constrained while the private sector has made tremendous technical progress. The result is the dawn of a new space industry. Where once America and Russia raced to the moon, now the competition is between entrepreneurs vying for business.

Much of that technical progress is driven by American entrepreneurs who made their fortunes outside aerospace. They funded startups that, to the surprise of many observers, started building actual rockets and spacecraft with budgets ranging from the tens to the hundreds of millions of dollars. Some, such as SpaceX and Bigelow Aerospace, have already begun testing hardware in orbit. Meanwhile, NASA has spent billions in failed attempts to replace the 30-year-old shuttle.

However, NASA deserves credit for finally shucking its indifference—and occasional hostility—to private space ventures and establishing its Commercial Crew and Cargo Program in 2006. Through development grants and contracts for trips to supply the International Space Station, the program has given the new space industry both money and credibility, helping it grow beyond the dreams of a few mavericks *(see "Entrepreneurs Challenge Aerospace Giants," p. 67)*. In return, NASA gets a chance to refocus its efforts on bold exploration.

The result has been a situation similar to the microcomputer revolution of the 1970s and 1980s or the dot-com boom of the 1990s: a diverse collection of systems are competing in a new, fast-growing market. Such explosions of innovation are typically followed by extinctions, but a handful of survivors, like Apple and Microsoft or Amazon and Google, prove truly transformative.

So, too, it may be with the current crop of space entrepreneurs as they seek customers beyond NASA supply contracts and the current trickle of super-rich tourists *(see "Will Customers Boldly Go?" p. 63)*.

—Stephen Cass

DATA POINT

$49.9 million

Cost of launching a satellite weighing under eight tons to low Earth orbit using SpaceX's Falcon 9 rocket.

GARY I ROTHSTEIN/EPA/CORBIS

SUPPLY RUN An artist's impression of Cygnus, a cargo spacecraft being built by Orbital Sciences.

TECHNOLOGY OVERVIEW

To the Space Station and Beyond

Entrepreneurial space companies are developing technologies that promise to put people and cargo in space more cheaply and frequently than has been possible with systems built and operated by governments, such as the American space shuttle or the Russian Soyuz.

These technologies can be divided into two classes: suborbital systems that will let tourists take an arcing flight above the atmosphere before falling back to Earth, and orbital systems designed to carry astronauts and cargo for longer trips into space, visiting destinations such as the International Space Station.

Getting to suborbital space is a lot cheaper than orbiting Earth; the rockets can be much smaller and don't need the heat shields required for reëntry from orbit. The trade-off is time: passengers are in space for only a few minutes. But companies like Blue Origin hope a few minutes of microgravity and spectacular views will be enough to lure enthusiasts and scientists. The company's New Shepard spacecraft combines a crew capsule with a propulsion module. After about two and a half minutes of boost, the New Shepard will shut off its engines and coast. The capsule and propulsion module will separate for landing, and the propulsion module can be jettisoned in case of problems during the ascent.

Safety is a big concern for companies that plan on carrying civilians. Virgin Galactic's SpaceShipTwo will use a hybrid rocket motor powered by a combination of solid and liquid fuels. The hybrid design retains much of the simplicity of a solid-fuel engine (the sort used to provide additional thrust to the space shuttle), but the burn rate can be carefully controlled in flight like that of a liquid-fuel engine, improving operational safety. SpaceShipTwo will be carried part of the way to space by the WhiteKnightTwo aircraft. This system is based on the one used by SpaceShipOne, which won the Ansari X Prize in 2004 by becoming the first private craft to complete a manned spaceflight *(see "Beyond Low Earth Orbit," p. 66)*. Virgin Galactic hopes to take its first passengers into space this year or early next year.

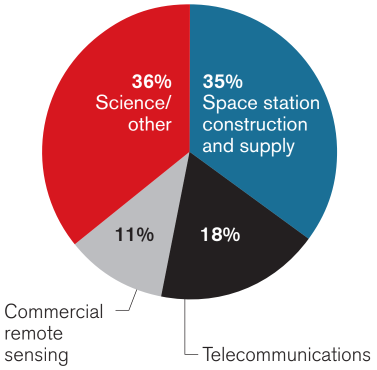
Some of the companies building orbital spacecraft are developing both the craft and the means to get them into space. Orbital Sciences' Cygnus cargo capsule, for example, will be boosted into low Earth orbit by the company's Taurus II rocket (which will also be used to launch satellites) and then use smaller motors to navigate to the International Space Station. Orbital has an eight-mission contract with NASA to carry supplies to, and waste from, the station between this year and 2015. Orbital plans to launch the Taurus II for the first time this summer, and it is also working on spacecraft designs that could carry astronauts.

ORBITAL SCIENCES

MANIFEST DESTINY

The needs of the International Space Station will drive a large portion of launches.

Global nongeosynchronous orbit launches by purpose, 2010–2019



Source: Federal Aviation Administration

SpaceX, too, is developing a paired capsule and propulsion system. The company is developing three versions of its Falcon launch vehicles, each with a different lift capacity; they will be able to send payloads (including satellites and probes) into low Earth orbit (where the space station is), geosynchronous orbit (used by many communications satellites), and beyond (for planetary exploration). The SpaceX Dragon capsule is being funded in part by NASA grants to develop a cargo spacecraft, but it is being designed so it can be easily upgraded to accommodate up to seven people.

Capsules are an efficient way to cram a lot of volume into a relatively small but strong structure. However, it's not possible to exert much control over where they land; they use parachutes to alight in the ocean or on some unpopulated patch of land. Sierra Nevada *(see "Chasing the Dream," p. 64)*, on the other hand, is developing an orbital vehicle that has a lifting-body shape, like an airplane. The Dream Chaser will be propelled into orbit by United Launch Alliance's Atlas V rocket and will use hybrid rockets for a controlled landing on airport runways.

—Katherine Bourzac

INDUSTRY CHALLENGES

Will Customers Boldly Go?

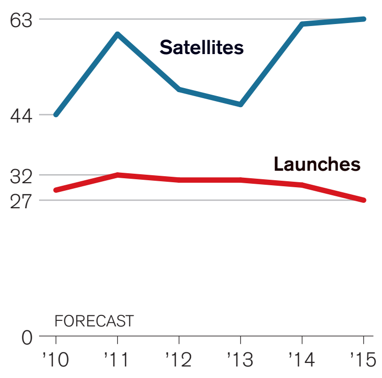
When NASA announced the Commercial Orbital Transportation Services (COTS) program in 2005, the agency was hoping for a way to send cargo—and, ultimately, crew—to the International Space Station less expensively than a government-built system could do. It also hoped it could kick-start a competitive market for these services among buyers other than itself, creating an orbital economy not solely dependent on federal funds. However, a question looms over this effort: how many customers besides NASA can be found?

It's unlikely that many new customers will come from existing markets, such as operators of satellites used for commercial communications or to monitor happenings on Earth. Global demand for satellite launches is forecast to be relatively flat for the next decade, according to a report published last year by an industry advisory group and the FAA. That market is well served by existing providers. The introduction of new rockets being developed for COTS, like SpaceX's Falcon 9 and Orbital Sciences' Taurus II, is unlikely to spur additional demand in the near term, although these vehicles may be able to capture business that has previously gone to the soon-to-be-retired Delta II rocket from United Launch Alliance, a joint venture of Boeing and Lockheed Martin.

FAILURE IS AN OPTION

Without new types of customers, there won't be significant growth in the launch market.

Forecast number of satellites and launches globally



Source: Federal Aviation Administration

AP PHOTO/NASA TV

SAY CHEESE Anousheh Ansari visited the International Space Station in 2006. Not only did she buy her own ticket to space, but she and her family partly sponsored the original $10 million X Prize.

Instead, vehicle developers are looking to new markets, notably space tourism. Over the last decade Space Adventures has flown seven commercial passengers to the ISS (one flew twice) at prices of up to $40 million each, taking advantage of extra seats on Russian Soyuz spacecraft. Last fall Space Adventures announced a similar agreement to sell additional seats on Boeing's proposed CST-100 commercial spacecraft.

Another potential customer is Bigelow Aerospace, the Las Vegas–based developer of commercial space-station modules. That company has focused not on space tourism

DATA POINT

390+

Number of people who have signed up for a suborbital trip into space with Virgin Galactic. Tickets cost $200,000 with a $20,000 deposit.

but on facilitating research by industrial concerns such as biotech companies and by "sovereign clients": countries without large space programs that could buy or lease a Bigelow station. Last fall the company announced memoranda of understanding with Australia, Japan, the Netherlands, Singapore, Sweden, and the United Kingdom. Sovereign clients may also be willing to buy flights directly from companies like SpaceX or Sierra Nevada, in part so that they can conduct their own missions without being a guest of the United States or Russia.

Yet it's been difficult to gauge the size of these potential markets. A 2002 study that I contributed to at the Futron Corporation (where I still work) forecast that demand for orbital space tourism would reach 60 passengers a year by 2021, but that assumed a ticket price of $5 million, well below current Soyuz prices. Similarly, though Bigelow Aerospace founder Robert Bigelow said last fall that he anticipates a demand of six flights a year for his first space station, he has announced no customers beyond the six countries that signed the memoranda.

The lack of details has fueled some skepticism about the prospects for commercial orbital human spaceflight. "The short-term prospects are miserable," says Henry Hertzfeld, a research professor at George Washington University's Space Policy Institute, who studies the economics of the launch industry. He believes that some companies will eventually find success in human spaceflight, primarily serving governments, but not anytime soon. "It doesn't add up to making a fortune on this stuff overnight," he says. *—Jeff Foust*

CASE STUDY

Chasing the Dream

The Sierra Nevada Corporation's entry into the new space industry is the Dream Chaser, a spacecraft the size of a business jet that it's building to take cargo and passengers—up to seven at a time—into low Earth orbit.

Although the craft is based on NASA designs, developing any vehicle is risky. And even if Sierra Nevada succeeds in building a working Dream Chaser, the company will face significant obstacles, says Scott Pace, director of the Space Policy Institute at George Washington University. Any new spacecraft will be unproven in terms of safety and reliability, so customers like the U.S. government (which so far has signed contracts only for transporting cargo) will be cautious about risking astronauts on a new design. It's a bit of a catch-22. "There is potential for the new vehicles to be safer than the space shuttle, but the only way you really know is by flying," says Pace.

Sierra Nevada has a little more room to navigate these bureaucratic shoals than some, because the firm has income from divisions that make a range of aerospace products. The privately held company, which was founded in 1963, employs about 2,100 people; it has been profitable for the past 13 years and had over $1 billion in revenue in 2010.

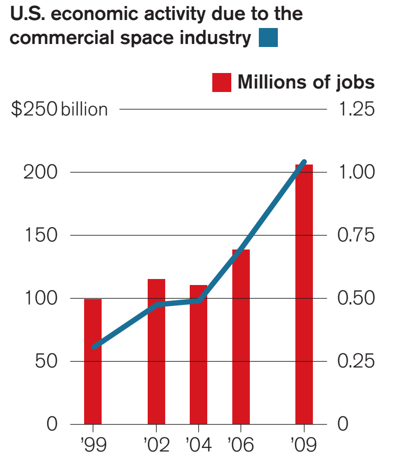
Mark Sirangelo, head of Sierra Nevada's space systems division, doesn't know when the Dream Chaser will be profitable. "We're entering an unknown world," he says. The company isn't disclosing exact figures, but Sierra Nevada has invested tens of millions of its own money in the project so far (offset somewhat by $20 million in development grants the company has received from NASA).

The company is designing the Dream Chaser so that each craft can be flown 50 to 100 times. Consequently, everything except the launch booster and the fuel cartridges is designed to be reused. In addition to trying to sell seats and cargo space to NASA for transport to and from the International Space Station, Sierra Nevada plans to go after space tourists, signing an agreement with Virgin Galactic to market orbital flights. Sirangelo also expects research institutes to buy room on the Dream Chaser to send experiments into space.

Last year, Sierra Nevada tested the Dream Chaser's frame and engines. This year, the company will drop the spacecraft from an airplane to see how it flies. The company is applying for a second round of NASA funding and expects to put a Dream Chaser in orbit by 2014. *—Katherine Bourzac*

ECONOMIC ASCENT

Despite the recession, the commercial space industry grew robustly.



Source: Federal Aviation Administration

BUILDUP Virgin Galactic's craft flies above spaceport construction.

MARK GREENBERG /VIRGIN GALACTIC

POLICY

The Crowded Skies

Spaceports are being built around the United States to facilitate a wave of space tourists, with six nonfederal spaceports already licensed in locations including New Mexico and Oklahoma. From these ports, companies such as Virgin Galactic and Blue Origin plan to operate spacecraft that will provide tourists with at least a peek above the atmosphere. That is causing a headache for the U.S. Federal Aviation Administration, which has to figure out how to integrate space flights into the national air traffic control system.

The problem is that pilots launching into space or returning home cannot make sudden changes in their craft's altitude and direction in response to an air traffic controller: after an initial rocket boost, most designs are unpowered, gliding or parachuting back to Earth. To avoid the potential for disaster, these flights have been conducted in "sterile airspace," which establishes a zone from which other aircraft are forbidden.

To date, because space launches are relatively infrequent, it has been possible to establish these zones as needed. But daily flights from multiple locations will necessitate a more systematic approach. The FAA began thinking about this issue in the late 1990s, and last August it established an industry-academic-government Center of Excellence for Commercial Space Transportation to develop new air traffic control rules (and settle other regulatory issues) for the commercial space industry.

Technical developments may also help. For example, Sierra Nevada's Dream Chaser is designed to use hybrid rockets for powered flight after reëntry, potentially allowing at least limited air traffic control.

—Stephen Cass

DATA POINT

60

Number of satellites the FAA estimates will be launched from Earth in 2011.

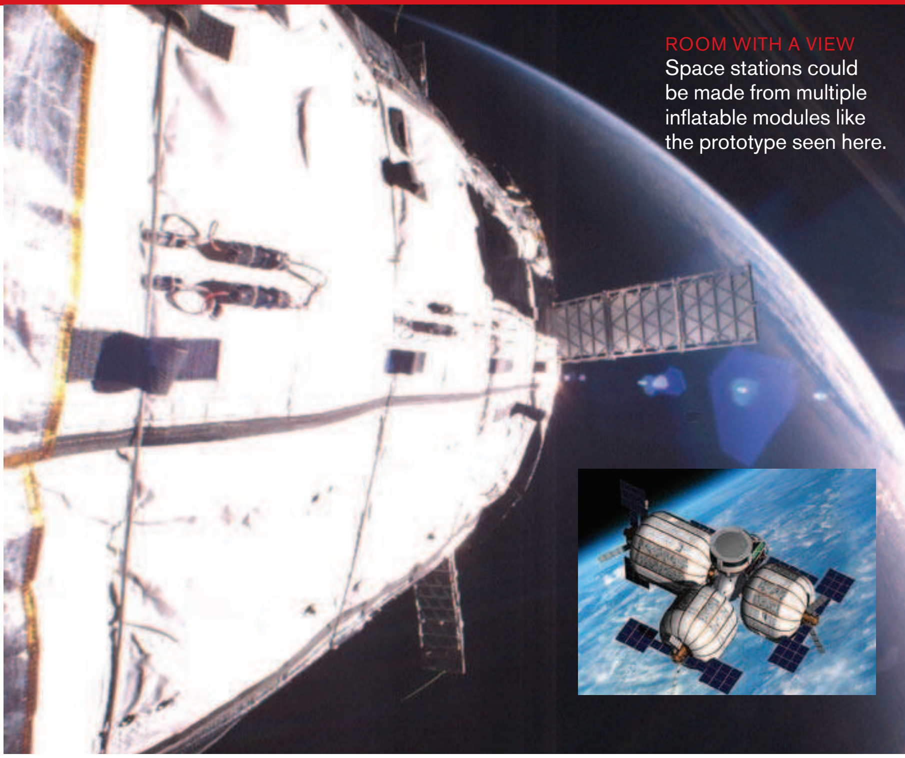
RUSSIA

Moscow Reopens for Space Tourism

The era of space tourism began in 2001, when the American multimillionaire Dennis Tito bought a ticket to the International Space Station aboard a three-person Russian Soyuz craft. Other private space travelers followed, but these trips were halted in 2009: the expansion of the station's crew from three to six required that all Soyuz seats be reserved for crew members.

However, the larger crew meant Russia had to expand its production capacity so it could launch four, rather than two, Soyuz spacecraft annually. In fact, with current capacity a fifth vehicle could be fabricated per year, if a customer willing to pay for the entire spacecraft shows up. These vehicles are the latest "digital Soyuz" model, which can be flown by a single professional cosmonaut, leaving room for two paying passengers—twice as many as previously. After fruitless negotiations last year with current station partners as well as Ukraine, Kazakhstan, India, and Malaysia, the Russians kicked off 2011 by signing a contract with Space Adventures, the firm that had managed the earlier tourist flights, to begin offering seats on the extra Soyuz in 2013.

Other recent announcements from Moscow have mentioned suborbital tourist hops by a rocket plane mounted atop an airliner (similar to Virgin Galactic's SpaceShipTwo) and an orbital hotel. But these are paper proposals. A more serious contender is the Excalibur Almaz project, which seeks to purchase, recertify, and fly a little-known type of spacecraft that was mothballed during the Soviet era. That effort has already attracted Western investors. *—James Oberg*



ROOM WITH A VIEW
Space stations could be made from multiple inflatable modules like the prototype seen here.

RESEARCH TO WATCH

Inflatable Habitats

Humans don't like to be cramped, but it's always been hard to fit large spacecraft or station modules on top of narrow rockets. In the 1960s NASA flew a satellite made of a flexible material that folded up tightly on top of the launcher. In orbit, the satellite was inflated to a diameter of over 30 meters. That could have become the basis for space station designs, but the concept fell by the wayside.

NASA revived the idea in the 1990s, when it was looking for ways to build a crew dormitory for the International Space Station. The agency hoped to build an inflatable shell made of layers of advanced materials, including Kevlar, packed together for insulation and strength; the result would protect against micrometeorites and space debris at least as well as a traditional metal module. Development was cancelled in 2000, but in 2004 Bigelow Aerospace bought exclusive rights to the technology, and two years later it launched an unmanned prototype habitat. It is still in orbit, collecting data on the module's long-term viability. Another prototype was launched in 2007. The company plans to start building a commercial space station made from inflatable modules in 2014, and it has a partnership with Boeing to provide transport to and from the station.

While Bigelow's development program continues, NASA is researching and testing designs suitable for human missions to the moon or Mars. *—Brittany Sauser*

DATA POINT

1969

Year that Pan Am established a waiting list for tourists wishing to fly to the moon; 90,000 people signed up.

OVER THE HORIZON

Beyond Low Earth Orbit

Robot explorers have ventured beyond low Earth orbit on scientific missions for decades, but it is still an expensive and relatively uncommon undertaking. However, "properly incentivized, the private industry can help make access to [the moon and beyond] low-cost and routine," says William Pomerantz, the senior director of space prizes at the X Prize Foundation.

The biggest incentives the foundation is offering come in the form of a competition among privately funded teams to launch a lunar exploration robot by 2015. The competition, sponsored by Google, will award $20 million to the first team to land, travel 500 meters, and send images and video back to Earth; $5 million to the second team to achieve those objectives; and $5 million worth of bonus prizes for achievements such as visiting an Apollo mission site. Nearly 30 teams have entered the Google Lunar X Prize competition; their estimated median mission budget is $50 million to $75 million. The prize money won't cover the costs for most of the entrants (in the original X Prize competition, the winner spent over $25 million to capture a $10 million award for the first private spacecraft), but sponsors are chasing the potential for glory and commercial spin-offs.

Although the competition is focused on encouraging private investment, NASA is paying close attention, says John Olson, a director in NASA's Exploration Systems Division. "We have a mutual interest in achieving more affordable and sustainable space exploration, and the competition is critical to that," he says. The agency has agreed to buy mission data from six teams. *—Brittany Sauser*

BIGELOW AEROSPACE

SPACE CAPTAINS Behind many startups are wealthy founders, including (clockwise from top left) Richard Branson (Virgin Galactic), Jeff Bezos (Blue Origin), Robert Bigelow (Bigelow Aerospace), and Elon Musk (SpaceX).

AP/STEFANO PALTERA (BRANSON); AP/MARK LENNIHAN (BEZOS); AP/PAUL SANCYA (MUSK); AP/LAURA RAUCH (BIGELOW)

MARKET WATCH

Entrepreneurs Challenge Aerospace Giants

By the late 1990s, after decades of consolidation, the aerospace industry in the United States was dominated by giant contractors Boeing, Lockheed Martin, and Northrop Grumman. Today, these and a few other companies, including Orbital Sciences and Space Systems/Loral, are responsible for constructing nearly all U.S. satellites and launch vehicles. The picture is similar globally, with only a handful of firms, such as Arianespace and Khrunichev, selling launch services and space hardware. But several startups, such as SpaceX and Virgin Galactic, have emerged to threaten their dominance by offering cheaper ways to get into space, even if only for a few minutes. SpaceX, for example, offers satellite launches on its Falcon 9 rocket starting at about $50 million, as little as half competitors' prices.

History is not on their side. In the late 1990s there was a similar burst of entrepreneurial activity in the launch industry when telecommunications companies planned to launch hundreds of satellites to service mobile phones. When the growth of terrestrial cellular networks decimated the customer base, however, these ventures collapsed.

Although the number of potential customer is still a cause for concern *(see "Will Customers Boldly Go?" p. 63)*, the new ventures are different from those that failed in the past. Many of them are focusing on suborbital spaceflight, which is cheaper and less technically challenging than sending vehicles into orbit and bringing them back *(see "To the Space Station and Beyond," p. 62)*. Whereas SpaceX has spent close to $500 million developing the Falcon 9 and Dragon spacecraft, some suborbital companies, like XCOR Aerospace, peg their development costs at $20 million or less. On the orbital side, they also have a stable anchor customer in NASA, which is pumping billions of dollars in development funds and supply contracts into the private space industry. Several of the startups have the backing of wealthy founders who have deep personal motivations to develop spaceflight. The presence of such entrepreneurs reduces the danger that skittish investors will jump ship.

"None of these things are themselves guarantees of success," says Charles Lurio, publisher of *The Lurio Report*, an industry publication. "But there are a lot more pillars supporting this set of ventures than there were in the '90s." Those factors are helping new companies attract business. Just days after the inaugural launch of the Falcon 9 last summer, SpaceX won a $492 million contract to launch Iridium's next-generation communications satellites, beating competitors like Arianespace.

Meanwhile, the startups' technical progress and the pot of NASA money have tempted established aerospace companies off the sidelines. Orbital Sciences is building a launcher and cargo spacecraft under a NASA contract that could be worth up to $1.9 billion, and Boeing has begun developing its own crewed spacecraft with $18 million in agency study funds. The United Launch Alliance, a joint venture of Boeing and Lockheed Martin that manufactures the Atlas and Delta rockets, has also received a study grant.

The result is a crowded marketplace, with many different systems in the works. NASA has previously acknowledged that a shakeout is likely in the coming years. If the resulting competition drives down the cost of spaceflight further, we may see more entrepreneurial activity in the future. Otherwise, it will probably be another 20 years before the giant aerospace contractors are challenged again. *—Jeff Foust*

THE BIG PICTURE

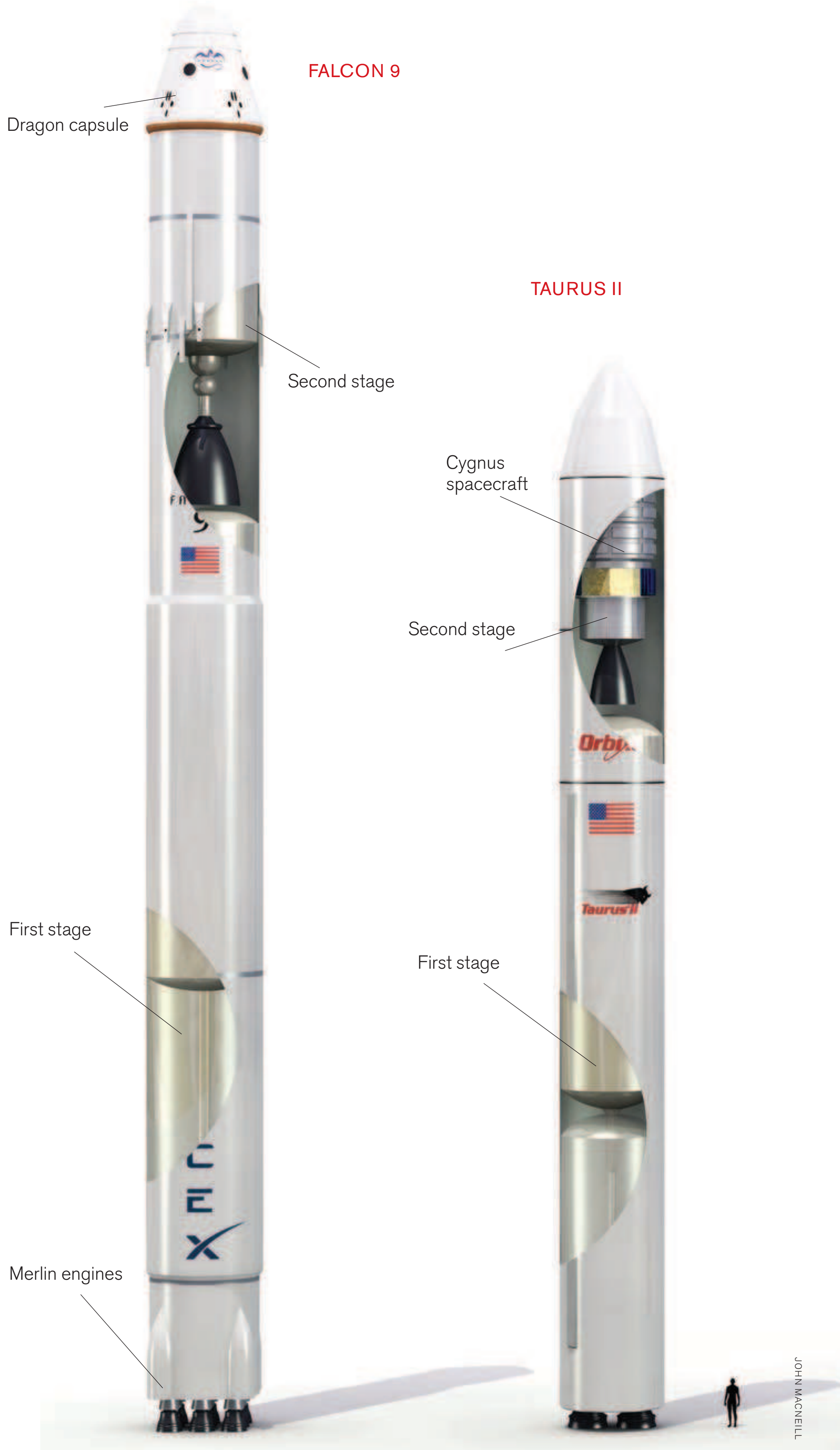
The Space Boom

There are now more types of rockets and spacecraft flying and soon to be flying than at any other time since the early days of the space race. The rocket with the longest private space travel record is the Russian Soyuz (far right), which was developed by the Communist Soviet regime in the depths of the Cold War. Although a third stage was added when it was adapted for manned spaceflight (Soyuz is also the name of the spacecraft that carries cosmonauts on top of the rocket), the Soyuz rocket has the same basic design as the rocket used to launch *Sputnik* in 1957. In 2001, millionaire Westerners started using Soyuz craft to fly to the International Space Station.

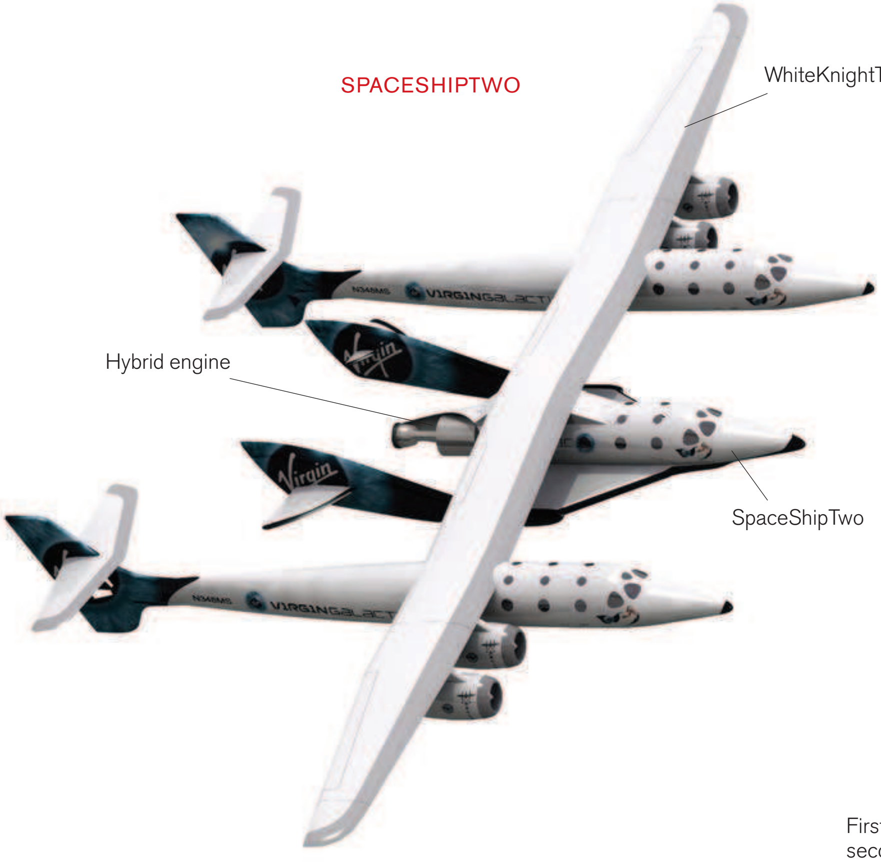
The first American spacecraft designed for private spaceflight was SpaceShipOne, which won the Ansari X Prize in 2004 by making two suborbital flights above Earth's atmosphere. Virgin Galactic is developing a scaled-up version for paying passengers; called SpaceShipTwo, it will be propelled by a hybrid rocket engine that combines elements of liquid and solid engines (second from right). An airplane called WhiteKnightTwo will carry the spacecraft above the densest parts of the atmosphere before ignition *(see "To the Space Station and Beyond," p. 62)*.

Two new rockets that can launch spacecraft and satellites into orbit are being developed by Orbital Sciences (second from left) and SpaceX (far left). They represent competing engineering approaches: Orbital has tried to use as much off-the-shelf technology as possible to reduce risk, while SpaceX has tried to build as many systems in house as possible—including a new Merlin rocket engine—to reduce costs.

—Stephen Cass



JOHN MACNEILL



WWW

Read about the latest developments in private spaceflight:
technologyreview.com/briefings/space

reviews

COMMUNICATIONS

Transparency and Secrets

WikiLeaks wants to undermine states and corporations by interfering with their ability to "think." It may not survive, but its innovations will be imitated.

By JASON PONTIN

How do we begin to make sense of WikiLeaks, the Internet organization that publishes the secrets of governments and companies?

Begin with its guiding spirit and tutelary genius. People like to say that WikiLeaks is "bigger than Julian Assange" (who describes himself as the organization's editor in chief), but they have interests that are parents to the thought. They hope to portray WikiLeaks as a popular force, or they are embarrassed or angered by Assange, who has a talent for alienating those with whom he works. In unguarded moments, however, Assange is more candid. In an online chat with one disgruntled WikiLeaks volunteer, he summarized the blunt facts: "I am the heart and soul of this organization, its founder, philosopher, spokesperson, original coder, organizer, financier, and all the rest." If we want to describe WikiLeaks, we must start with its creator.

Wikileaks.ch

"State and Terrorist Conspiracies"
"Conspiracy as Governance,"
by Julian Assange

OpenLeaks

Al Jazeera's Transparency Unit

WHAT WIKILEAKS IS

When Assange conceived WikiLeaks in 2006, what was he thinking? At the time he was obscure: 35 years old, the product of a deracinated Australian childhood, famous only within the computer hacker subculture, and earning his living as a freelance software developer and white-hat hacker. In fact, we can recover his intentions, because two short essays he posted late that year on his now blank personal Web page have been preserved on cryptome.org, a repository of cypher-hacker documents. These essays are primary texts for any understanding of WikiLeaks: they are, in Assange's own description, "motivational," and he wrote them before he became guarded and disingenuous.

"State and Terrorist Conspiracies" and "Conspiracy as Governance" are extraordinary documents: supple, original, and, it must be declared, nuts. They are written in a strange, epigrammatic, abstracted prose, as if Theodor Adorno had picked up network theory by hanging out with the comp-sci kids at the University of Melbourne. Assange begins by quoting that 17th-century wit the first Lord Halifax—"The best kind of party is but a kind of conspiracy against the rest of the nation"— and goes on to define all authoritarian regimes, including the management of corporations, as conspiracies.

In imagining how such conspiracies "compute," Assange draws upon the mathematical concept of "connected graphs," and he explains the concept's application to conspiracies by asking us to imagine a board with nails and twine. The conspirators are nails; the twine, the communications between them.

Traditionally, a resistance movement employed assassins, but Assange insists that nothing so unsubtle could undo a modern conspiracy. Instead, he recommends that activists degrade the conspiracy's ability to "think." We can decrease a conspiracy's "total conspiratorial power," Assange writes. "We can split the conspiracy, reduce or eliminating [sic] important communication[s] between a few high weight links or many low weight links."

Although WikiLeaks is often described as a "whistle-blower site," Assange cares less about the content of leaks than about what leaking does to conspiracies. Still less was WikiLeaks invented to further some Internet ideology of "radical transparency": Assange accepts that individuals have rights to secrecy. Rather, he conceives of WikiLeaks as an insurrection whose rebellions are leaks. He writes, "The more secretive or unjust an organization is, the more leaks induce fear and paranoia in its leadership and planning coterie. This must result in minimization of efficient internal communications mechanisms (an increase in cognitive 'secrecy tax') and consequent system-wide cognitive decline resulting in decreased ability to hold onto power."

Assange's big idea is unchanged: as recently as last April he said, "We are an

THE INSURRECTIONIST Julian Assange outside a London court in January. He was fighting extradition to Sweden, where he is wanted on allegations of sexual assault.

AP PHOTO/LEFTERIS PITARAKIS

activist organization. The method is transparency, the goal is justice."

How WikiLeaks works is more easily described. Assange himself, with obvious pride of authorship, has been forthcoming, if secretive about the details. The technologies are complicated but not new. WikiLeaks's primary website is hosted on servers managed by PRQ, the same nonjudgmental Swedish Internet service provider that serves the BitTorrent site The Pirate Bay and various pedophiles' fora, and it is mirrored on around 1,400 other sites. Sources can upload documents to WikiLeaks using a version of the TOR network, which permits the anonymous transfer of files over the Internet, in combination with some undisclosed form of encryption, which disguises their content. It is this combination of an irrepressible website, TOR, and encryption that constitutes the innovation of the "secure drop box": together, they make WikiLeaks a kind of platform from which leaks cannot be traced and cannot be censored. The suspected source of the most sensational WikiLeaks material, a U.S. Army private named Bradley Manning, was caught only because he bragged to a former hacker who turned informer.

WikiLeaks has published a bewildering number of documents: to date, around 20,000 files, according to the organization. Nevertheless, those files constitute only a fraction of the documents WikiLeaks claims it possesses but has not yet released. (The reason seems to be sheer incapacity. The organization is small and underfunded, with too few staff and volunteers to validate, evaluate, and format the flood of submissions.)

Many of the published documents are neither very secret nor newsworthy. They did not have to be, given the goal of WikiLeaks; it was enough if conspiracies were made to feel porous. From 2006 to 2008, WikiLeaks published the U.S. Army's protocols for the Guantánamo detention center; the e-mails of U.S. vice-presidential candidate Sarah Palin; allegations of malfeasance at the Cayman Islands branch of a Swiss bank—and much more. In 2009, it released a report about an accident at the Iranian nuclear facility; instructions from the British Ministry of Defense explaining how to secure military computer systems from WikiLeaks and foreign spies; documents from a bank deeply involved in the Icelandic financial crisis—and, again, much more.

But 2010 was the year WikiLeaks began to live up to Assange's ambitions. The organization posted a highly edited classified U.S. military video depicting what it called "the indiscriminate slaying of over a dozen people in ... New Baghdad, including two Reuters news staff," and it began to release more than 391,000 reports from soldiers in the field in Afghanistan and Iraq and more than 251,000 secret, confidential, and unclassified diplomatic cables. This year, WikiLeaks has released more documents belonging to a Swiss bank, and Assange says his next target will be a major American bank, probably Bank of America.

An abiding mystery about WikiLeaks is the degree to which it was founded upon a hack, or is still a hack. According to a profile of Assange in the *New Yorker,* an unnamed "WikiLeaks activist" managed a server that was a node in the TOR network at some time

before the launch of the organization. The activist "noticed that hackers from China were using the network to gather foreign governments' information, and began to record this traffic." If the story is true, this initial windfall of hacked documents is what let Assange claim, at the site's foundation, "We have received over one million documents from 13 countries." It is technically possible to record an unencrypted data packet on the TOR network, but WikiLeaks stoutly denied the charge. Yet the suspicion persists that Assange has returned to his hacking roots. In January, Bloomberg reported that Tiversa, a computer security company, had "evidence" that WikiLeaks was hacking peer-to-peer file-sharing networks, in a fashion that Tiversa's researchers called "both systematic and highly successful." Assange, through his lawyer, denied this charge, too.

WHAT WIKILEAKS ISN'T

Julian Assange doesn't want anyone to think of his creation as the world's biggest hack. Instead he talks about WikiLeaks as a "media organization" that publishes journalism.

In part, this is pretension. Better to be the editor in chief of a news site practicing an innovative form of "scientific journalism"—an intellectual of world-historical importance!—than a thief or pimp. Assange can become testy when reminded of his hacker background. He darkly told *Forbes*, "But that was 20 years ago ... It's very annoying to see modern day articles calling me a computer hacker. I'm not ashamed ... But I understand the reason they suggest I'm a computer hacker now. There's a very specific reason."

And in truth, WikiLeaks has become more like a media organization as it has evolved. At its founding, there was some thought that ordinary people would organize and interpret the documents the organization published; anything could be submitted. This crowdsourcing suggested the name "WikiLeaks." But since December the wiki functions have been turned off; the editor in chief decides which leaks are sufficiently important to publish.

The crowd disappointed him, and Assange won't trust it again. At a 2010 seminar on the future of journalism, he explained:

> Our initial idea was ... look at all those people editing Wikipedia. Look at all the junk they're working on. Surely, if you give them a fresh, classified document about the human rights atrocities in Falluja, ... surely *those* people will ... do something. No. It's all bullshit ... People write about things in general (if it's not part of their career) because they want to display their values to their peers ... They don't give a fuck about the material ... Very early on, we understood ... that we would have to at least give summaries of the material we were releasing ... to get people to pick it up ... In cases where ... the material is more complex ... it's not even enough to do a summary. You have to do an article, or ... liaise with other journalists ... Otherwise it goes nowhere.

This is misleading. There are only two dozen such "articles" on Wikileaks.ch, and they read less like journalism than like corporate press releases: mostly short, self-aggrandizing, overheated documents that quote WikiLeaks spokespeople. In fact, the organization relies upon large, professional media organizations such as the *New York Times*, the *Guardian*, *Le Monde*, *El País*, and *Der Spiegel* to do the heavy work.

Assange has good reason to represent himself as an editor and WikiLeaks as a media organization: he doesn't want to go to jail. In countries that enjoy strong protections for freedom of speech and the press, leakers can be prosecuted for crimes including espionage and theft, but the media cannot be punished for publishing leaks. Assange knows the U.S. Department of Justice is considering whether it can bring a case against him. At issue: did WikiLeaks solicit classified materials or hack computer systems, or was it merely a passive publisher of leaked materials?

WikiLeaks is not a media organization, except (possibly) legally, insofar as it publishes. It produces little original writing, video, radio, or any other editorial product, because it does no reporting, analysis, or criticism. It employs neither journalists, editors, and art directors nor any of the businesspeople who develop audiences and sell advertising. Media organizations are institutions where professionals collaborate laboriously to make and sell useful and sometimes beautiful things. They are accountable to their audiences, to their business partners, and to the laws and mores of the societies in which they are incorporated. What does WikiLeaks make? What does Julian Assange want? To what is WikiLeaks accountable, except to Assange's outraged rectitude?

Perhaps the best way to conceive of WikiLeaks is like this: it is a stateless, distributed intelligence network, a reverse image of the U.S. National Security Agency, dedicated to publicizing secrets rather than acquiring them, unconstrained and answerable to a single man.

THE FUTURE OF WIKILEAKS

If WikiLeaks is not a media organization, is it another example of the Internet overthrowing our settled habits? That question is more interesting. By this formulation, WikiLeaks is to the state and corporations what Napster was to music or Google is to media as a business.

Shakespeare, Lord Annan recalled in his war memoirs, gave to Ulysses in *Troilus and Cressida* the haunting phrase "There is a mystery ... in the soul of the state." "That mystery is the intelligence services," Annan explained. He was thinking of his service on the United Kingdom's Joint Intelligence Staff 70 years ago. But the modern state has many allied organizations besides the intelligence services, including the management of large corporations and banks, who partake in its mystery. Julian Assange, the disordered soul of WikiLeaks, wants to explode the soul of the state.

The modern state, with its monopoly on violence, is not like the music industry or the media. It is properly jealous of its secrets, and more powerful and able than Assange understands. It will bitterly resent an attack by a crypto-utopian on its ability to "think." Assange has declared himself the state's enemy, and he will, in all

likelihood, be comprehensively destroyed. WikiLeaks will vanish.

Once imagined, however, the technology of WikiLeaks cannot be forgotten and can easily be imitated. Other organizations, less radically activist, will create secure drop boxes for anonymous leaking. Already, the disgruntled former WikiLeaks volunteer, Daniel Domscheit-Berg, has said he will create a less threatening platform called OpenLeaks. It will, he says, publish nothing but, instead, function as a pipeline where sources designate the media organization to which they wish to leak: "We want to be a neutral conduit. That's what's most politically sustainable." Still more leak platforms are sprouting, including GreenLeaks, which will publish "information of environmental significance"; Brussels Leaks, which will expose the European Union; and Rospil, which will uncover Russia's secrets.

Predictably, media organizations want to replicate WikiLeaks's secure drop box, too. Recently, Al Jazeera launched a "Transparency Unit," which encourages its audience to submit "all forms of content" for "editorial review and, if merited, online broadcast and transmission on our English and Arabic-language broadcasts." The first product came in January, when Al Jazeera published the "Palestine Papers," 11 years' worth of secret documents created by the Palestinian Authority, describing negotiations with the Israeli government. The impression that emerges from them is that the Israeli government is no longer interested in securing a Palestinian state: it is a scoop that could not have existed without the Transparency Unit's drop box. Now other publications are considering their own. Bill Keller, the executive editor of the *New York Times*, is pondering how he can make it easier for sources to leak to his journalists.

WikiLeaks may not be with us for the long haul, but others will imitate its innovations, and they are likely to be more constrained and more responsible. tr

JASON PONTIN IS *TECHNOLOGY REVIEW*'S EDITOR IN CHIEF.

JASON SCHNEIDER

PRIVACY

How to Stop the Snoopers

Getting advertisers to quit tracking you may be harder than you think.

By SIMSON L. GARFINKEL

Most of us depend on free Web services, from Google searches to Facebook updates. Unless you're careful, though, using them has a price: your privacy. Web advertising pays for almost all such services, and this business has become very efficient, delivering ads to grab your attention. That requires tracking who you are and what you do online. Your Web browser reveals a surprising amount about you, and advertisers are keen to find out even more.

Protecting Consumer Privacy in an Era of Rapid Change: A Proposed Framework for Businesses and Policymakers
Preliminary FTC staff report
December 2010

The government's principal consumer protection agency, the Federal Trade Commission, has taken the first major step toward addressing this situation with a new draft report that recommends the creation of a "Do Not Track" mechanism that would let Internet users choose, with the click of a button, whether to allow advertisers to track them online. This would offer better privacy controls than exist currently. But ultimately, the FTC's approach falls short of what's needed. That's because tracking technology is interwoven into our most popular websites and mobile services. Without tracking, they simply don't work.

Few people realize that many of today's Web ads are tailored using huge amounts of personal data collected, combined, and cross-referenced from multiple sources—an approach known within the industry as "behavioral advertising." This tracking goes far beyond offering product recommendations based on your purchase history. Behaviorally targeted ads reflect which sites you have visited over the past month (or longer) and what you've done on those sites. Web advertisers employ a bewildering variety of tracking technologies. Perhaps the best-known involves small text files, or "cookies," that are invisibly downloaded to your computer when you visit a site; other sites then access the cookies to determine where you've been. This can provide advertisers with clues to where you live, where you work, which sports teams you follow, which TV shows

you watch. Advertisers can then refine their ads accordingly.

Behavioral advertising works. Two years ago a team of scientists at Microsoft Research Asia and two Chinese universities analyzed 17,901 Web advertisements shown to more than six million search-engine users over a seven-day period in June 2008. They found that users were up to seven times likelier to click on behaviorally targeted ads. It's hardly surprising, then, that these ads earn much more for websites—an average of $4.12 per thousand views versus $1.98 per thousand for regular ads, according to a study of 2009 data commissioned by the Network Advertising Initiative, a trade group that promotes self-regulation.

There's just one problem: most people find the very idea of behavioral advertising offensive—at least, they do once they learn it's happening. A recent survey of 1,000 U.S. adults conducted by professors at the University of Pennsylvania and the University of California, Berkeley, found that 73 percent of respondents thought it was "not okay" for advertisers to tailor ads on a website according to what they did on that site. And 84 percent said it was "not okay" for the advertisements they saw on one website to reflect what they had done on another site.

While many are simply opposed on principle to unrestricted tracking, there are real risks to data aggregation that we are just beginning to understand. Without safeguards, the tracking techniques used by advertisers could be exploited to steal identities or to devise ways to hack into computers. And the big databases that advertisers are building could be misused by unscrupulous employers or malicious governments.

Over the past 15 years the United States has developed a peculiar approach to protecting consumer privacy. Companies publish detailed "privacy policies" that are supposed to explain what information they collect, how, and what they plan to do with it. Consumers can then choose whether they want to provide their information—and they're welcome to avoid certain websites entirely.

The FTC draft report says that this model no longer works (if it ever did). "Many companies are not disclosing their practices," FTC chairman Jon Leibowitz said at a press conference in December when the report was released. "And even if companies do disclose them, they do so in long, incomprehensible privacy policies and user agreements that consumers don't read, let alone understand." Behavioral advertising makes this notion of "choice" even more dubious, since information collected on one site may be used on countless others.

The FTC is trying to rein this in. It recommends, for example, that companies collect information only when there is a legitimate business need to do so, and asks them to destroy that information when they no longer need it. But many U.S. companies operate the opposite way: collect everything possible and store it indefinitely in the hope that the data might prove useful someday.

The report says that companies need to do a better job of explaining their policies to consumers. One possible alternative to lengthy and hard-to-read privacy notices would be a simplified "privacy label," modeled on nutrition labels. A privacy label would present a website's policies in an easy-to-understand, easy-to-compare format. But requiring privacy labels on commercial websites would probably require an act of Congress—something that seems unlikely to happen.

Of course, real choice requires more than just clear information—it also requires options. At the moment, that means taking measures such as activating the "private browsing" mode built into modern Web browsers (which prevents sites from accessing cookies) or using browser plug-ins that automatically block advertisements and certain tracking technologies.

But there is no rule that says advertisers can't employ their own measures to circumvent private-browsing modes, and many are doing so. Browsers can be "fingerprinted," using their unique settings, allowing tracking without cookies. Advertisers can even sniff the history directly out of your

browser, by exploiting the way Web links are displayed in a different color once they have been clicked. Last summer, researchers at Stanford University's Security Lab presented a paper comparing the private-browsing modes of the four most popular Web browsers: Internet Explorer, Firefox, Chrome, and Safari. They found ways to defeat these modes, including a new type of cookie that can be accessed via Adobe's ubiquitous Flash plug-in—meaning that "private" browsing is never really private.

The FTC's solution to this problem is "Do Not Track." The idea is loosely modeled on the agency's popular "Do Not Call" list. Instead of a centralized list of consumers who don't want to be tracked, however, the report envisions a browser setting that would transmit an anonymity request to Web advertisers. If behaviorally targeted advertisements really are beneficial to consumers, most people will leave the feature switched off. Otherwise, websites better get used to $1.98 per thousand ads viewed.

Browser makers have started building tracking controls for their software. Google recently released an add-on for Chrome called Keep My Opt-Outs, and Microsoft has announced a similar feature for Internet Explorer 9 called Tracking Protection. Mozilla promises to add similar functions to Firefox. These features all tell websites when someone doesn't want to be tracked. But it's still up to companies to honor this request. And, unsurprisingly, the idea of "Do Not Track" is fiercely opposed by the advertising industry, which warns it would hamstring a booming business—especially if enabled in browsers by default.

The real problem with "Do Not Track," however, is that it derives from an earlier understanding of Web advertising—that ads are distributed by advertising networks to news sites, search engines, and other destinations that don't necessarily need to know who you are. Nowadays many popular websites are unusable unless you let them track you.

Take Facebook: the site has seen explosive growth in advertising revenue precisely because it tracks its users' interests in great detail. There's no way to turn off tracking and still let your friends see your status updates. Thanks to Facebook Connect, which lets you log on to other websites with your Facebook credentials, and the "Like" button, which sends links from external Web pages back to your Facebook profile, Facebook now tracks you across the Web. Or, more accurately, you tell Facebook where you are.

Smart phones will accelerate this trend. Already, many phone apps deliver ads based on your GPS-determined position. Future ads might depend on the applications that you've installed, whom you've called, even the contents of your address book—all information that's there for the taking. With the popular geography-based social-network game Foursquare, the only way to avoid tracking is not to play.

There is a way to resolve this conundrum, and it's disappointing that the FTC report ignores it. The report recommends continuing to try to limit what information companies can get, instead of limiting what they can do with information once they have it. In this age of Facebook, Google, and Foursquare, what we actually need are simple and enforceable policies limiting the retention and use of consumer data. These could be dictated by the government or, conceivably, built into browsers so that users could decide on the specifics. For example, you could tell Google that it may archive your searches forever, to help improve its service, but that it has to anonymize them after six months. You could tell Facebook it can keep your posts indefinitely but can use them for advertising purposes only for a year.

Unfortunately, any kind of reform will face stiff opposition from vested interests. But if the government wants to defend us from privacy-trampling advertising, it needs more than "Do Not Track": it needs to consider limitations on the use of Web data. tr

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INTERNET

It's Good to Be the Mayor

Foursquare and other new location-based social games on mobile phones can be compelling, but only when they harness the energy of the countless offline games we're already playing.

By MATT SCHWARTZ

It's an old retail trick: encourage people to buy things by turning consumption into a game. From the Green Stamps coupon program to frequent-flier miles, loyalty bonuses have been businesses' way to reward customers in hopes of prodding them to buy even more. But now this technique is taking on a new and potentially more powerful form by exploiting the ubiquity of GPS-enabled smart phones and their users' love of video games. More and more, businesses can use game elements—virtual points, levels, and challenges—to boost demand and shape consumer behavior.

Foursquare
Scvngr

One prominent startup behind this trend is Foursquare, which offers a smartphone app that asks people to "check in" at bars, restaurants, and clubs. Foursquare awards points for check-ins and anoints the person who accumulates the most for one place during a certain period as the "mayor" of the location—a title that usually confers no benefits other than bragging rights. Foursquare has several competitors in the check-in game, including Gowalla, Brightkite, Whrrl, and Booyah. Another company, Scvngr, aims to take the concept further: its intense 22-year-old founder, Seth Priebatsch, likes to describe his goal as "building a game layer on top of the world."

Game-ifying everything could become broadly popular, but only if the virtual prizes matter within our real-life social networks. Think of why Facebook works: it enhances and expands existing social connections. Something similar could happen with apps that offer games to play while you're out and about. The real world is already overflowing with dynamics that amount to fascinating and complex social games, and apps will succeed by tapping into them rather than by trying to invent something entirely new.

Consider Foursquare. The game that drives its traffic was around long before the app. It is played in text messages and phone calls and can be traced back further, to guest books, gossip columns, and restaurant seating plans. This game might be called "What's Going On Tonight?" The objects: meet the right people, avoid the wrong people, maximize fun. How to play: exchange information about your whereabouts (current and planned) with trusted friends. All Foursquare did was put this game on a smart phone and add one ingenious tweak—letting someone win the title of mayor.

It took Twitter two years to accrue its first million users; Foursquare did it in less than 14 months. Nine months later, it claims nearly six million registered users who check in 1.5 million times each day. This explosive growth attracted $20 million in a funding round led by Andreessen Horowitz. "A check-in is even more simple than sending a tweet," says Naveen Selvadurai, Foursquare's cofounder. "But it's so loaded with data. You're saying to businesses, 'Hey, I'm here—do you want to send anything special to me?' You're telling your friends, 'This would be a great place to meet up.' You're intimating a certain amount of intent." Foursquare's app shows some ads, but the company's business model is still a work in progress. For now the company is focusing mainly on traffic growth.

Scvngr says it will hit the million-user mark even faster. It has also attracted about $20 million in funding, including significant backing from Google Ventures. Scvngr charges businesses monthly fees of $80 to $1,080 for premium listings that allow them to pose "challenges" to customers. In Scvngr's standard example, customers at a burrito joint could be asked to fold their tinfoil wrapper into a piece of origami, take a picture of it, and upload it in exchange for Scvngr points, which can eventually be used to unlock rewards such as coupons. Beginning on "Black Friday," the retail-obsessed day after Thanksgiving, Scvngr worked with Coca-Cola to create a series of location-based challenges at malls, like high-fiving other Coke drinkers. Top players could win gift cards.

I tested these services in Portland, Oregon, by strolling down NW 23rd Avenue, a trendy strip of boutiques. I tapped my phone to check in on Foursquare at establishment after establishment (checking in is on the honor system, and you can check in anywhere, but Foursquare will suggest places near where you happen to be). I also earned points on Scvngr for posting whatever photos and text struck my fancy. There didn't seem to be much to it. At Powell's City of Books, one of the world's largest independent bookstores, Scvngr offered me a challenge called "our little secret." "Climb the ranks from patron to regular," the app urged, "by obtaining information about a special dish that is not listed on the menu." The app was mistakenly categorizing Powell's as a restaurant. I typed in "books." Scvngr awarded me four points. I was supposed to feel proud. I felt nothing.

Foursquare's app indicated that none of my Facebook friends who use the service were in the vicinity, so for a while I tried awkwardly approaching strangers like Carly Katherine L. at Little Big Burger, who graciously explained that her only Foursquare connections are three or four close friends. Asking her to add me would have been a hopeless overreach. But then again, Foursquare isn't meant to be an icebreaker, because a Foursquare friend is far more intimate than many Facebook friends. You're

doing more than sharing your CV and vacation photos. You're revealing your physical location. This isn't something you want to share with those hundreds of acquaintances known to sociologists as "weak ties." Foursquare friendship is necessarily limited to people with whom you might actually want to hang, right now. For users, that means a smaller potential pool of connections, yielding a slower stream of updates. But there would also seem to be longer-term value for businesses, because the stronger ties mean that tips passed from one user to another are likely to carry more weight. After all, the news that someone you like is at a particular restaurant, and excited enough to broadcast that news, is a powerful endorsement.

Foursquare guided me to Wieden + Kennedy, Portland's marquee ad agency, which it identified as a "trending" location—meaning that it was seeing a cluster of check-ins. Standing in front of Wieden's castle-like doors was an acquaintance, Aaron Rayburn, a 29-year-old designer and artist. Our meeting happened by old-fashioned coincidence—although Aaron is a serious Foursquare user, with 34 friends and four mayorships, including one at Portland's Chinatown gate, he is selective about check-ins. Foursquare had no idea that he was visiting W+K. In fact, of the hundreds of employees who work in the firm's Portland office, only six had checked in. Aaron whipped out his iPhone 4 and located the nearest happy hour. We were soon checking in at Vault, a cocktail lounge. One drink later, we were Foursquare friends, and he had started to explain the site's appeal.

"When birds come back to the nest at night, they share information," he said. "Where's the food? How much is there?" He picked up his phone and acted out his part of the information-sharing. "'Right now I'm out hunting and gathering at Vault. And it's really great! You should come too.' Foursquare scratches this itch that's very ancient."

Scvngr, on the other hand, tends to get users to do things for companies or organizations rather than for each other. Jewelers have used Scvngr to send couples on hunts for diamond rings. Museums, conferences, and college orientations have used Scvngr treks as icebreakers. There's no equivalent to Aaron's bird analogy—a compelling reason for someone outside one of these manufactured frameworks to play. Until Scvngr develops that, it will not resemble a game layer so much as a new form of marketing.

Jamin Brophy-Warren, cofounder of the gaming magazine *Kill Screen*, says this distinction is crucial. "Foursquare's endgame is getting people out in the world and connecting with each other," he says. "That's different from a brand-first approach, where your goal is getting people to interact with a product. In the long term, it's going to compromise the game."

THURSTON HOPKINS/HULTON ARCHIVE/GETTY IMAGES

One proof of Foursquare's deep appeal is that some people artificially boost their point totals by repeatedly checking in at venues without actually being there. Rob Z. of Portland, one of the accused, has racked up 6,169 check-ins, 56 badges, and 107 mayorships. "Please stop this guy," one user pleaded on a Foursquare message board. "PDX is a great foursquare town and he is ruining it for us all." Yes, the few yellow pixels that denote a badge are so desirable that someone is willing to cheat to get them, and someone else is willing to call him out on it.

It's because the real object of desire—being known as the most regular of all regulars at your local—is a prize that was around well before you could tweet about it. Silly as it may seem, the glowing crown of a Foursquare mayorship shows the way forward for "real-world" games of tomorrow. The best ones won't need to build a new layer on top of the world. They'll find an especially rich old layer and mine it. tr

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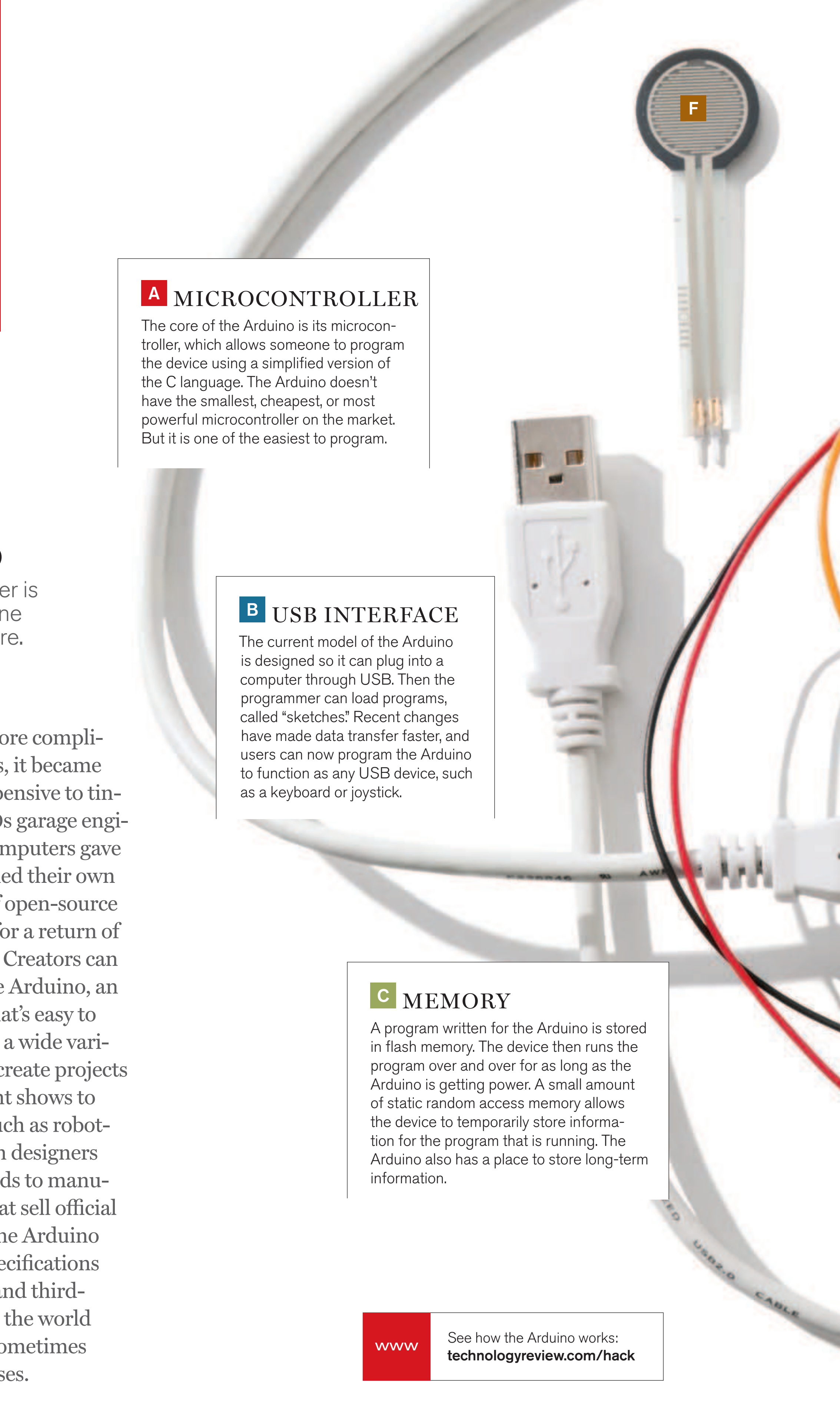
hack

Arduino Uno

How a cheap microcontroller is making it possible for anyone to design and build hardware.

By ERICA NAONE

AS ELECTRONIC DEVICES got more complicated in the past few decades, it became increasingly difficult and expensive to tinker with hardware. The 1970s garage engineers who built their own computers gave way to geeks who programmed their own software. But now the rise of open-source hardware is paving the way for a return of build-it-yourself electronics. Creators can start with devices such as the Arduino, an inexpensive control board that's easy to program and can hook up to a wide variety of hardware. People can create projects that range from blinking light shows to more sophisticated efforts such as robotics. The Arduino started with designers in Italy, who license the boards to manufacturers and distributors that sell official versions for less than $50. The Arduino designers freely share the specifications for anyone to use, however, and third-party manufacturers all over the world offer versions of their own, sometimes optimized for specific purposes.



A MICROCONTROLLER

The core of the Arduino is its microcontroller, which allows someone to program the device using a simplified version of the C language. The Arduino doesn't have the smallest, cheapest, or most powerful microcontroller on the market. But it is one of the easiest to program.

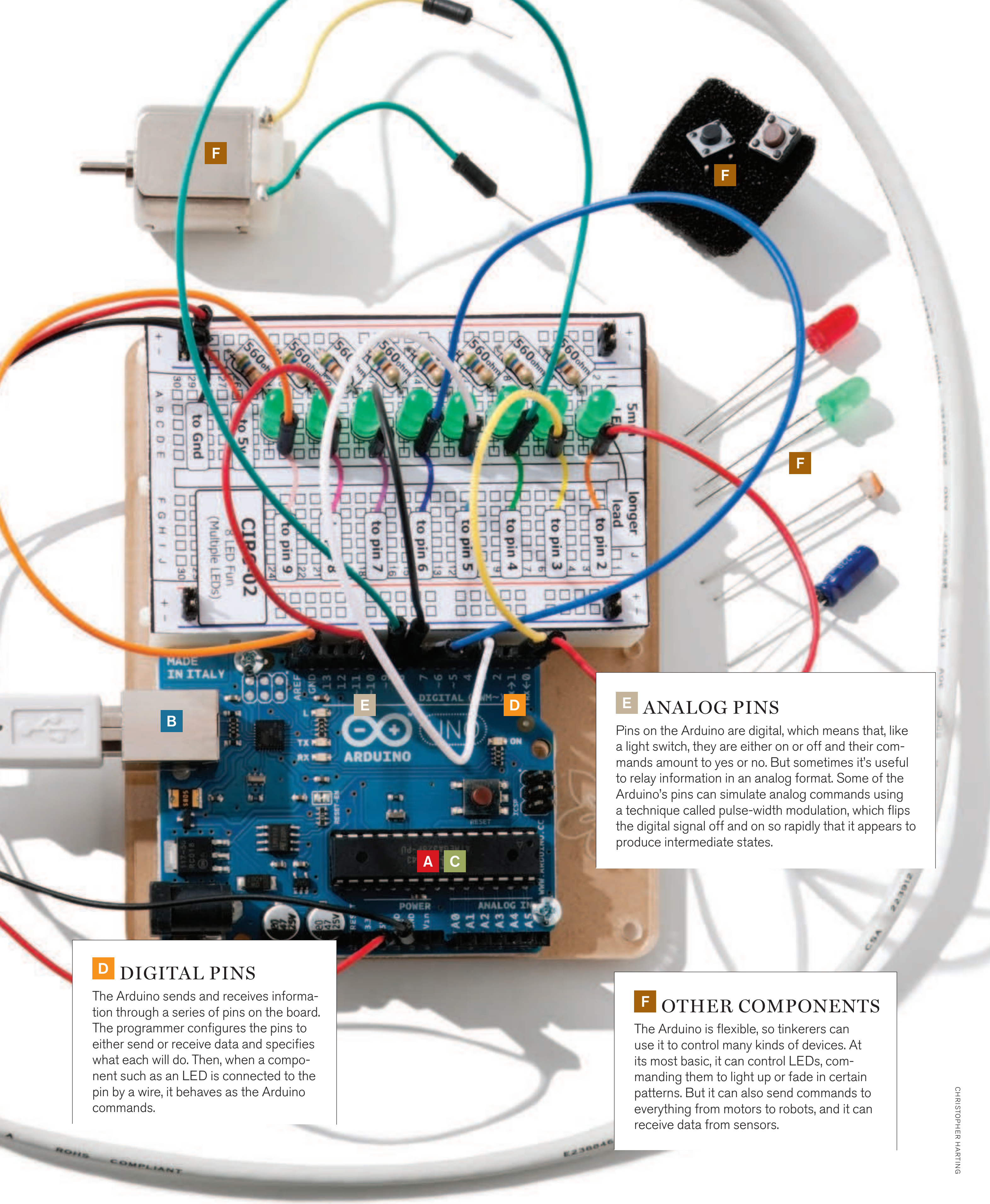
B USB INTERFACE

The current model of the Arduino is designed so it can plug into a computer through USB. Then the programmer can load programs, called "sketches." Recent changes have made data transfer faster, and users can now program the Arduino to function as any USB device, such as a keyboard or joystick.

C MEMORY

A program written for the Arduino is stored in flash memory. The device then runs the program over and over for as long as the Arduino is getting power. A small amount of static random access memory allows the device to temporarily store information for the program that is running. The Arduino also has a place to store long-term information.

WWW See how the Arduino works: **technologyreview.com/hack**



CHRISTOPHER HARTING

E ANALOG PINS

Pins on the Arduino are digital, which means that, like a light switch, they are either on or off and their commands amount to yes or no. But sometimes it's useful to relay information in an analog format. Some of the Arduino's pins can simulate analog commands using a technique called pulse-width modulation, which flips the digital signal off and on so rapidly that it appears to produce intermediate states.

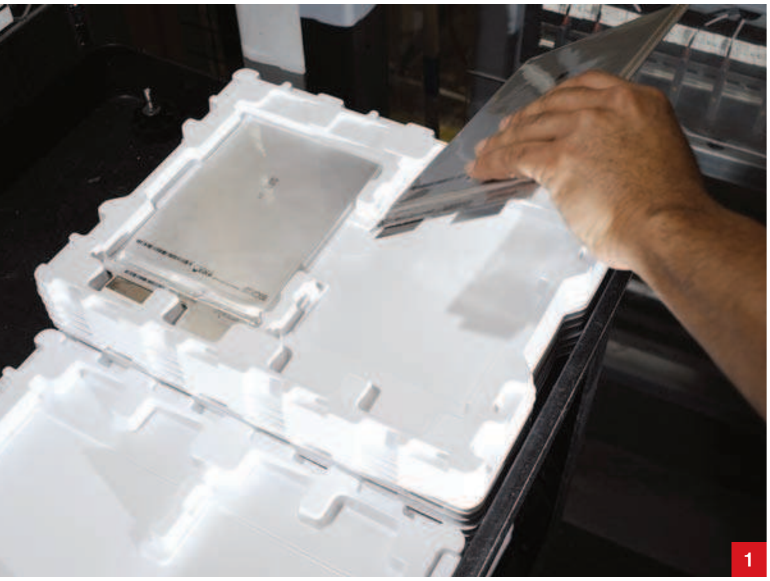
D DIGITAL PINS

The Arduino sends and receives information through a series of pins on the board. The programmer configures the pins to either send or receive data and specifies what each will do. Then, when a component such as an LED is connected to the pin by a wire, it behaves as the Arduino commands.

F OTHER COMPONENTS

The Arduino is flexible, so tinkerers can use it to control many kinds of devices. At its most basic, it can control LEDs, commanding them to light up or fade in certain patterns. But it can also send commands to everything from motors to robots, and it can receive data from sensors.

demo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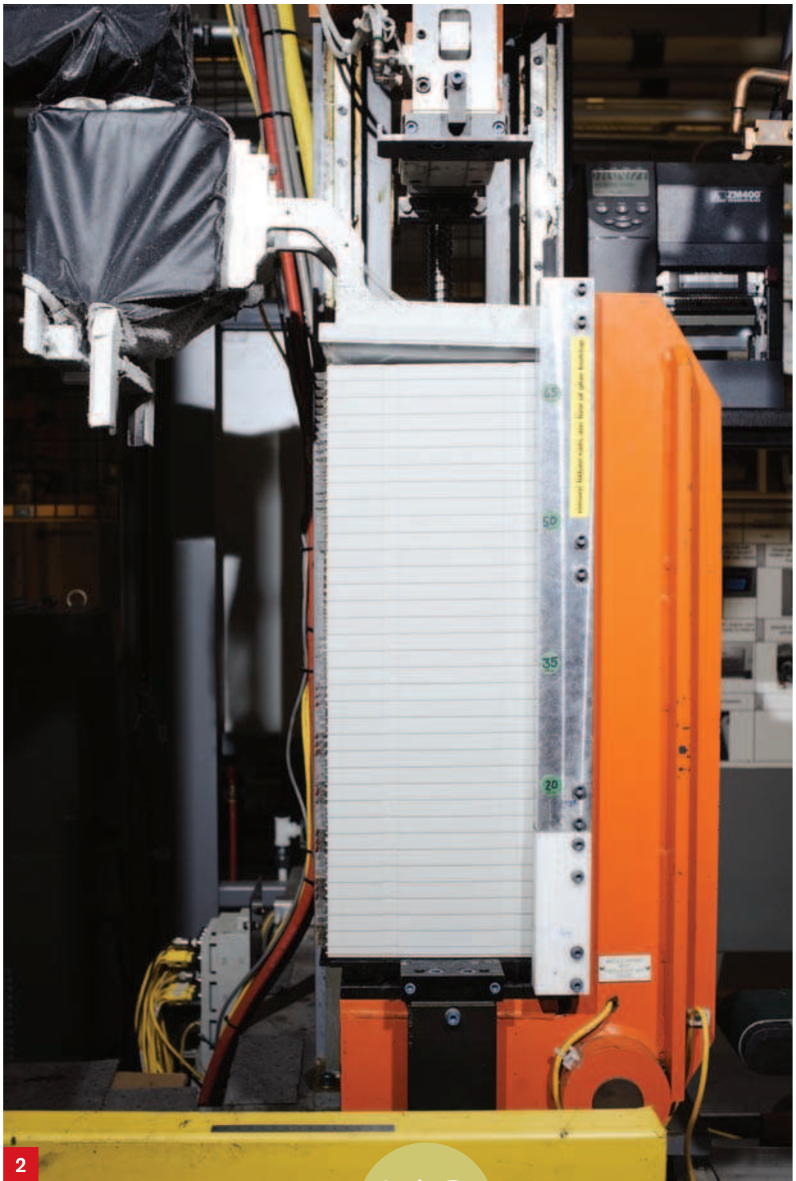
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Building Batteries for Electric Cars

A123's new factory exploits automation and advances in nanotechnology.

By KEVIN BULLIS

Quentin Sharpe, a technician in A123 Systems' new battery factory in Livonia, Michigan, takes a foil packet out of a white plastic container and sets it down within reach of a robot, which scoops it up and adds it to a growing stack of metal plates and foil packets. It's the start of a process that makes one of the dozens of types of battery packs assembled here—all of which will power advanced hybrid and electric vehicles designed to cut petroleum consumption.

Production of advanced lithium-ion batteries for electric cars and hybrids has so far been dominated by companies in Asia, but the U.S. government hopes to see it become a major new industry in the United States. The new factory will have the capacity to produce 30,000 battery packs a year once all its equipment is up and running (A123's plans call for the factory to be fully operational by this spring). It is one of nine that the U.S. Department of Energy helped fund in a $2 billion program created under the American Recovery and Reinvestment Act of 2009. A123 received $249 million in government funding for two facilities, which it matched with additional money from private sources. "Just a few years ago American businesses could only make 2 percent of the world's advanced batteries for hybrids and electric vehicles—just 2 percent," President Obama said when he called in to the factory's opening ceremony last fall. The new factories are meant to

PHOTOS: ROY RITCHIE; INSET RIGHT: FABRIZIO COSTANTINI

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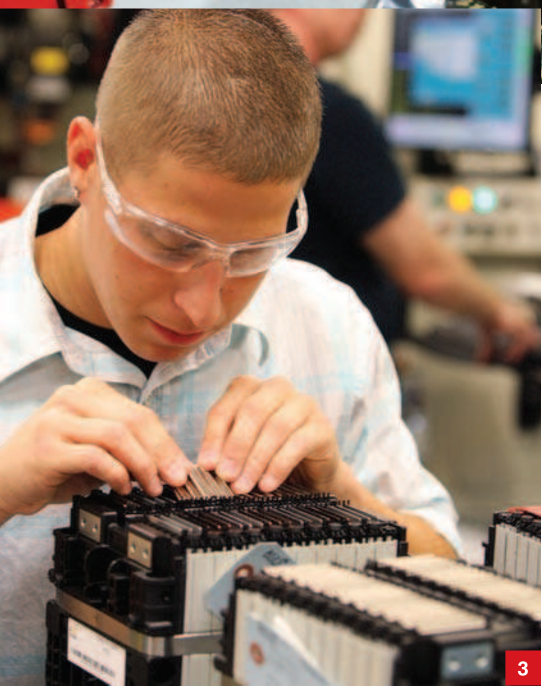

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1. Battery construction begins with the basic building blocks of the pack—the battery cells. Each of these flat silvery packets contains positive and negative electrode foils separated by a polymer sheet soaked with an electrolyte. The tabs emerging from the edge are positive and negative electrical contacts. The composition of the positive electrode is A123's key technology—it's a nanostructured material, made of lithium iron phosphate, that's designed to be safer and more resilient than the electrode materials commonly used in portable electronics.

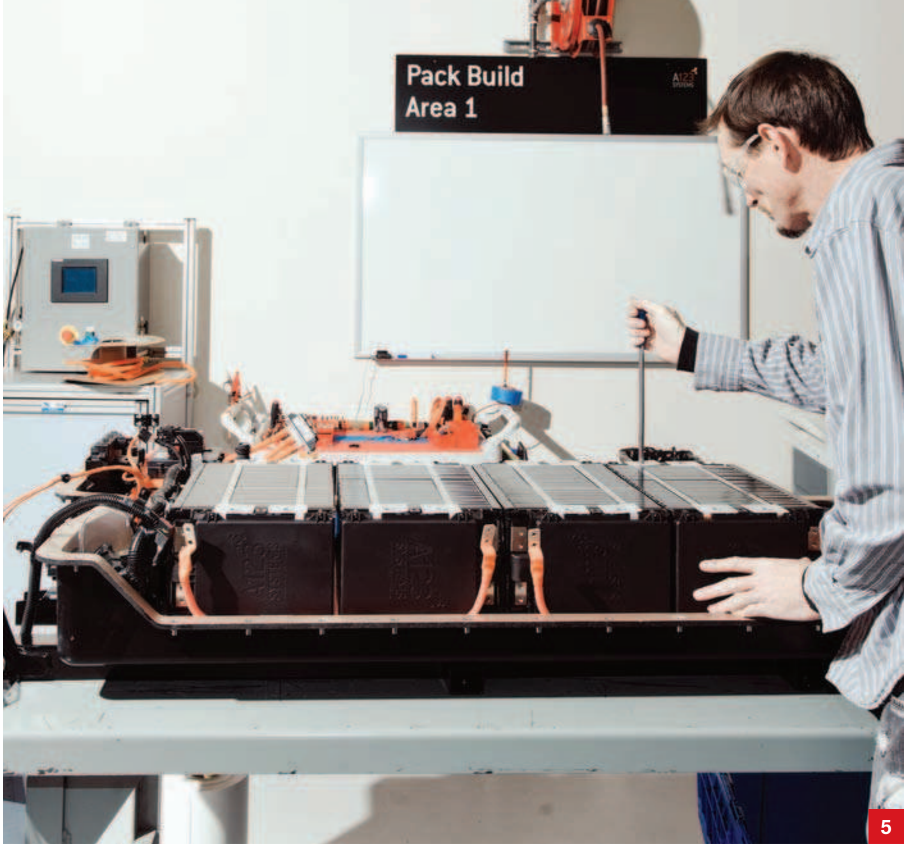
2. A robot (the gripper arm is shown at the top left of the photo) is used to create precisely aligned stacks of cells and metal heat sinks. Here the robot places a heat sink on top of a nearly complete stack. There are two cells per heat sink; their electrical connections can be seen on the left of the stack.

3. After a stack is complete, workers cap the ends with black plastic and bind the stack with metal straps. The size of a stack—also called a battery module—varies depending on the application. Groups of small modules, such as this one for the Fisker Karma sport sedan, are used when packs must fit into confined spaces. They're also used for starter batteries. Larger ones, like the stack in the previous picture, can be used for larger electric vehicles, such as delivery vans. Here, a worker adds a bus bar to the module. These pieces of metal connect the electrical contacts of the individual cells.

4. In the next step, dozens of temperature and voltage sensors are added to the pack. This picture shows the wires leading from these sensors down the middle of the pack to a white plastic connector. The connector plugs into an electronics board that monitors the sensors and communicates with the battery pack's central controller. The charging of each cell can be controlled separately to ensure that the cells are not overcharged, which could damage them. The temperature is controlled by a liquid cooling system.

5. Technician Rodney Richards installs a completed battery module inside the housing of the battery pack, next to three other modules. The modules sit on their sides, on top of what looks like a solid slab of aluminum (obscured). The slab is plumbed with tubing for coolant that keeps the cells within an optimal temperature range—a key to making them last the life of a vehicle. To keep the pack cool, the coolant flows past the modules and then through a radiator. In some applications, a heater warms up the coolant on cold days.

6. This is an example of one type of completed battery pack. It's mounted on rails that can be bolted to a vehicle. Coolant flows in through ports on the back of the pack. A123 won't say exactly what vehicle this pack is designed for, citing confidentiality agreements with its customers.



help increase the U.S. share to 40 percent of the world's capacity.

That hope could be a long shot. Besides facing stiff competition from manufacturers in Asia, U.S.-based factories have to contend with a challenge inherent in new industries: no one knows exactly what kinds of cars powered by the new batteries will sell, or how well. Thus it's unclear which batteries, or how many of them, need to be built.

To address that uncertainty, A123 has designed a flexible factory that can make many different kinds of lithium-ion battery packs. All begin with the same basic building block: a battery cell in the form of the foil packet that Sharpe fed to the robot. By varying the number of cells, their arrangement, and the electronics that control them, A123 can produce batteries with a wide range of sizes and electrical properties.

Versions as small as a six-pack of beer can power "micro-hybrids" whose engines shut off whenever the vehicle comes to a stop and start again when the driver touches the accelerator. In that scenario, the batteries provide bursts of power to restart the engine, and in some designs they can store energy from braking. Other battery packs as big as bookshelves store enough energy to allow electric delivery vans to complete their routes on battery power alone.

This year A123 will start manufacturing thousands of battery packs for six different vehicle models, beginning with the Navistar E-Star delivery van and the Fisker Automotive Karma—a full-size luxury sport sedan that uses electric power to boost acceleration and to power gas-free commutes. The company is also preparing to make batteries for two Chinese passenger vehicles, a medium-duty utility truck, and several micro-hybrids, and it's making prototypes for dozens more vehicles. tr

www See the factory in action: **technologyreview.com/demo**

PATENTS, PENDING!

Under United States law, intellectual property primarily comprises patents, copyrights and trademarks.

Generally, a patent for an invention is the grant of a property right to the inventor, issued by the United States Patent and Trademark Office. The patent excludes others from making, using, selling or offering for sale the patented invention for a limited time period, typically twenty years.

So what can be patented? In the language of the United States patent statute, any person who "invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent," subject to the conditions and requirements of the law.

Patent protection in a given country does not extend to other countries - inventors must file an application in each territory where they want their patent to be effective. To maintain the validity of a patent, the owner needs to pay fees to each appropriate patent authority and failure to do so causes the patent rights to lapse.

Usually, patents can only be enforced through civil lawsuits. The patent owner will seek monetary compensation for past infringement, and will seek an injunction prohibiting the defendant from engaging in future acts of infringement.

Then, how does a company begin the process of protecting its intellectual property? To receive a patent, an applicant (or company) must file an application with the United States Patent and Trademark Office. Upon the trademark office's decision that the invention is new and non-obvious, it will issue the patent.

There are some other basic steps a company can take to ensure that its intellectual property is secure. Examples include instituting uniform policies requiring all employees to sign proper agreements. All newly developed technologies should be documented and kept confidential until a registered patent attorney has evaluated potential patent rights. For patented technologies, the company should mark all products with notice of the issued patent and aggressively pursue potential infringers.

In addition the company should monitor all maintenance fees to ensure that they are timely paid to keep all federal rights valid.

Finding your way through the patent and intellectual property maze can seem daunting. It needn't be.

Remember, without the protection of a patent, trademark or copyright, you might find out too late that you're walking a tightrope with no net.

A few interesting patents include:

- ***July 7th 1790:*** Samuel Hopkins for Potash – the first recorded US patent
- ***October 10th 1849:*** Walter Hunt for the safety pin
- ***July 14th 1868:*** Alvin J. Fellows for the spring tape measure
- ***2nd February 1906:*** Willis H. Carrier for air conditioning
- ***13th September 1955:*** George De Mestral, for Velcro

from the labs

INFORMATION TECHNOLOGY

Light Chips

Combining optical and electrical circuits should speed supercomputers

SOURCE: "CMOS INTEGRATED SILICON NANOPHOTONICS: ENABLING TECHNOLOGY FOR EXASCALE COMPUTATIONAL SYSTEMS"
William Green et al.
SEMICON, December 1–3, 2010, Tokyo, Japan

RESULTS: IBM researchers used standard fabrication methods to create a silicon chip that incorporates silicon photonics alongside conventional electronic transistors. These optical components can pipe data into the chip as a light signal, convert it into an electrical signal that can be processed by conventional components, and then convert it back into light to be sent out of the chip.

WHY IT MATTERS: The speed of supercomputers is constrained not by processing power but by limits on how fast data can travel down the electrical wires that link up different chips. Light signals move significantly faster than electrical ones, so using them could remove that bottleneck. While other groups have made silicon components that can process light, their designs cannot usually be integrated into the standard manufacturing processes used to make a chip's transistors.

METHODS: Light-processing components are typically much larger than electrical ones, so the researchers tried to shrink them as much as they could to keep the overall chip's design compact. One important modification was to drastically reduce the thickness of the germanium in a photonic component that detects light signals. The material is required to efficiently absorb light, but too much germanium would cripple nearby transistors by changing the behavior of the electrons that flow through them.

NEXT STEPS: So far the chips have been made only in a lab, but the IBM team is working to make them in a commercial foundry to prove that they can be manufactured cheaply and in large volume.

DUAL USE This chip contains optical and electrical circuits. Combining the two could move data faster.

IBM

Predicting Popularity

Mapping the popularity of tweets and blog posts foretells the fate of future posts

SOURCE: "PATTERNS OF TEMPORAL VARIATION IN ONLINE MEDIA"
Jaewon Yang et al.
Proceedings of the ACM International Conference on Web Search and Data Mining, February 2011

RESULTS: Researchers at Stanford University built a model that can predict, with 75 percent accuracy, when a new piece of online content's popularity will peak and how long it will last.

WHY IT MATTERS: The ability to predict how widely a news story or tweet will travel could help identify the most influential blogs and Twitter posters, providing clues to who might be able to disseminate an important piece of information most broadly. Websites could use the predictions to position their content and advertising, possibly increasing click-through rates.

METHODS: The researchers analyzed 170 million news articles and blog posts over the course of a year, as well as 580 million Twitter posts over eight months. They measured the attention each piece of content received by tracing how much it was mentioned elsewhere over time. They found that they were able to graph these patterns in a small set of distinct shapes. Some stories spike rapidly

and then fall off, making a sharp, pointed shape. Others have more staying power, rising and falling more gently. Observing early response to a new piece of content allows the researchers to predict what shape the graph of its influence will take and, thus, to predict its popularity and staying power.

NEXT STEPS: The researchers are investigating when and how errors are introduced into accounts of news stories and how content changes as it travels—for example, when quotes from public figures are dispersed. They are also trying to understand the networks by which information spreads, determining the exact path it takes across the Internet. These findings could help trace information to its source and reveal which sites are truly influential.

MATERIALS

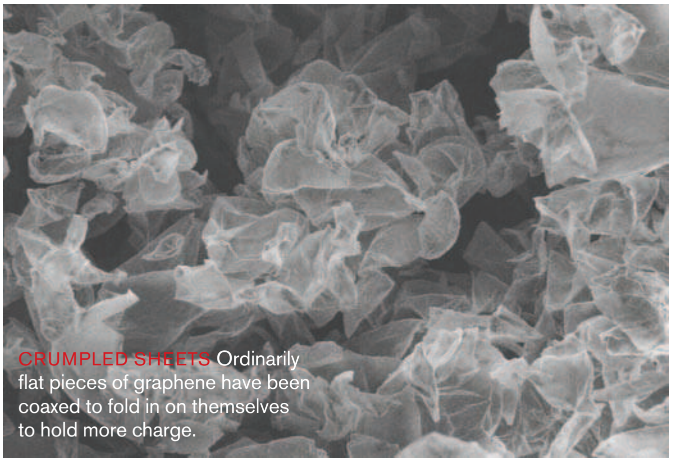
Graphene Electrodes for Hybrids

Atom-thick sheets of carbon make high-energy capacitors

SOURCE: "GRAPHENE-BASED SUPERCAPACITOR WITH AN ULTRA-HIGH ENERGY DENSITY"
Bor Z. Jang et al.
Nano Letters 10: 4863–4868

RESULTS: Using graphene, a form of carbon made of sheets just a single atom thick, researchers have built ultracapacitor electrodes that can store nearly as much energy as the electrodes now used in batteries for hybrid vehicles. The electrodes stored 86 watt-hours per kilogram. That would translate to 21 to 43 watt-hours per kilogram in a complete ultracapacitor, which would weigh more than just the electrode. Nickel–metal hydride batteries for hybrids store between 40 and 100 watt-hours per kilogram.

WHY IT MATTERS: Automakers typically oversize the batteries in hybrids to make up for the loss of energy storage capacity over time as well as the fact that batteries can't be discharged completely without damaging them. Conventional ultracapacitors don't have this problem—they can be charged and discharged tens of thousands of times without losing much storage capacity—but they store just 5 to 10 percent as much energy as nickel–metal hydride batteries. The new high-energy electrodes could allow ultracapacitors to compete with nickel–metal hydride batteries. Although they still store less energy overall, more of their capacity can be used. And since they don't have to be oversized to compensate for the loss of capacity over time, they could be cheaper than batteries.



CRUMPLED SHEETS Ordinarily flat pieces of graphene have been coaxed to fold in on themselves to hold more charge.

BOR JANG/ACS

METHODS: Increasing the surface area of an ultracapacitor electrode boosts storage capacity because more of the ions in a liquid electrolyte are able to reach it. Graphene has high potential surface area, since it is so thin. But the thin sheets tend to stack up, blocking access to their surfaces. The researchers had previously developed a way to make the graphene sheets crumple so that they can't stack closely, making it easy for the electrolyte to reach its surfaces. In the latest study, they showed that electrodes made with the crumpled graphene performed better than those made with ordinary graphene and activated carbon.

NEXT STEPS: The researchers are continuing to refine the shape and dimensions of the graphene to improve performance, and they plan to work with others to develop cheaper electrolytes. They are scaling up the production of their graphene, with the goal of commercializing it within two to three years.

Bacteria Begone

Coating for artificial joints protects against infection

SOURCE: "DUAL FUNCTIONAL POLYELECTROLYTE MULTILAYER COATINGS FOR IMPLANTS: PERMANENT MICROBICIDAL BASE WITH CONTROLLED RELEASE OF THERAPEUTIC AGENTS"
Paula Hammond et al.
Journal of the American Chemical Society 132(50): 17840–17848

RESULTS: A multipart polymer coating for the surface of a medical implant can prevent bacterial infection over time. Antibiotics released from the surface kill microbes in the short term, and an underlying antimicrobial polymer permanently bound to the surface prevents bacterial colonization over longer periods. When submerged in a solution of strep, a piece of silicon treated with the coating resisted the growth of bacteria as the drugs dissolved and, after they were gone, over a period of two weeks.

WHY IT MATTERS: Infections resulting from joint-replacement surgeries are rare but can be deadly. When they happen, surgeons must remove the joint and any

infected areas and wait six to eight weeks for a course of drug treatment to be completed before a second replacement can be attempted. This complication raises the cost of a joint replacement, which averages $30,000 in the United States, to as much as $150,000. Infections can also occur many years after the initial surgery when bacteria enter the bloodstream, such as during a colonoscopy or a dental procedure. Antimicrobial coatings developed for static implants, such as stents, do not work for artificial joints because a thick coating interferes with their movement.

METHODS: Researchers at MIT started with an existing implant whose structural antimicrobial coating pierces bacterial cells that try to land on the surface. They added layers of a biodegradable polymer, an antibiotic, and an anti-inflammatory drug by dipping the implant alternately in solutions of negatively and positively charged polymer and drug molecules. The differences in charge hold the layers together, creating a coating—just tens of nanometers thick—with a high concentration of antimicrobial drugs. The drugs are released as the polymer degrades inside the body. The process could be adapted to add different drugs.

NEXT STEPS: The chemical engineers are working with clinicians at Boston's Veterans Hospital to determine whether this process improves outcomes after joint replacements in small animals.

MEDICINE

Drug-Resistant Cancers

Scientists discover how some tumors become immune to medications

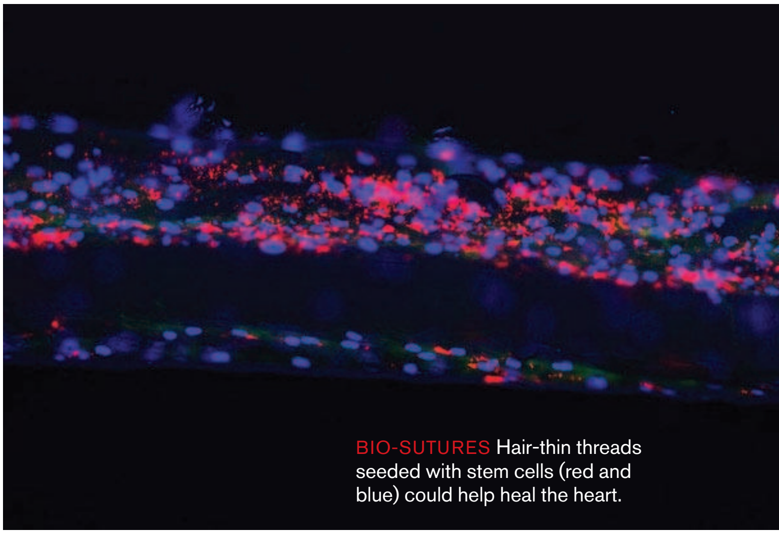
SOURCE: "COT DRIVES RESISTANCE TO RAF INHIBITION THROUGH MAP KINASE PATHWAY REACTIVATION"
Levi A. Garraway et al.
Nature 468(7326): 968–972

RESULTS: Researchers from the Dana-Farber Cancer Institute uncovered specific cellular changes that allow melanoma tumors to become resistant to a previously effective drug.

WHY IT MATTERS: Targeted cancer drugs, which are designed to block the effects of genetic mutations that drive the growth of cancer, can be life-saving for patients with those mutations. But eventually—whether it takes months or years—every cancer evolves resistance to these drugs. New insight into the genetic changes underlying this process will aid in the design of new drugs and drug combinations that could allow targeted therapies to work longer and maybe even overcome resistance altogether.

METHODS: Researchers analyzed the effects of 600 different protein kinases, a type of enzyme, on melanoma tumor cells growing in a dish. They found that overactivity among nine of the protein kinases—including one that had never previously been implicated in cancer—made the cells resistant to a melanoma drug to which they had once been vulnerable. The researchers confirmed the findings by analyzing tissue samples from melanoma patients who became resistant to the drug.

NEXT STEPS: The researchers need to confirm their findings in a larger number of patients. They also plan to look for additional mechanisms of drug resistance by expanding their search beyond protein kinases.



BIO-SUTURES Hair-thin threads seeded with stem cells (red and blue) could help heal the heart.

GAUDETTE LAB, WPI

Biological Sutures

Cell-seeded fibers might help heal the heart

SOURCE: "FIBRIN MICROTHREADS SUPPORT MESENCHYMAL STEM CELL GROWTH WHILE MAINTAINING DIFFERENTIATION POTENTIAL"
Glenn Gaudette et al.
Journal of Biomedical Materials Research Part A 96(2): 301–312

RESULTS: Researchers at Worcester Polytechnic Institute developed biological sutures made up of polymer strands infused with stem cells. They showed that the cells can survive on the threads and maintain their ability to differentiate into different cell types. They also showed that the cells remain on the sutures after being sewn through a collagen matrix that mimics tissue.

WHY IT MATTERS: Animal research suggests that delivering stem cells to damaged cardiac muscle after a heart attack can help heal the heart, but human studies have shown only modest or transient benefits. Researchers hope that new delivery methods will help the cells remain at the injury site in large enough numbers and for a long enough time to exert more substantial effects.

METHODS: The sutures are made from hair-thin threads of fibrin, a protein polymer that the body uses to heal wounds. The strands are transferred to a tube filled with stem cells and growth solution; the tube slowly rotates so the stem cells can adhere to the full circumference of the suture. Once populated by cells, the suture is attached to a surgical needle.

NEXT STEPS: The research team is now studying the sutures in rats' cardiac muscle to determine how long the cells remain at the injury site and whether they can help heal tissue. tr

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Digital Watches and Pet Rocks

The long-term value of an innovation often doesn't become apparent until it has gone through many product cycles—including buggy versions that annoy early adopters.

By KRISTINA GRIFANTINI

One reason why it's hard to predict the fate of a new technology is that it's too tempting to focus on bugs in an early version. We forget to look for the bigger underlying idea that will become apparent as the problems get solved.

Take something as ordinary as a digital watch. As absurd as it may seem now, when the first ones emerged in the early 1970s, people wondered whether consumers would be able to make the mental leap to telling time by digital numbers. Besides that, the contraptions had problems that made them seem as if they might become a passing fad.

In January 1977, *Technology Review* weighed in on the situation. By that time digital watches had been available for half a decade, although the earliest models were specialty items: the first one available to the public, a gold Pulsar LED created by the Hamilton Watch Company and Electro/Data in 1970, sold for $2,100. Not until 1976, when Texas Instruments made plastic LED watches that sold for $19.95, did digital watches start appearing on the wrists of everyday people.

But even by then, success was no sure thing. The 1977 *TR* column was in response to a *Consumer Reports* survey of 635 digital-watch owners. The survey showed that many weren't so pleased with what they'd bought.

For a while, it appeared as if our headlong race into the 21st century would be timed with a digital watch. The electronic devices are being turned out by the millions and snapped up by buyers. But lately indications are that the digital watch is but a fleeting craze, and the bright, blinking watch faces will vanish with platform shoes and pet rocks.

CAN I GET YOUR DIGITS? The first digital wristwatch ever mass-produced sold for $2,100.

Many complained that the digitals are hard to read. One type of display, the Light Emitting Diode (LED), depends upon a button which is pressed to light the numerals and tell the time; each button press drains the watch's battery. The other type, the Liquid Crystal Display (LCD), is visible without button pressing, but is impossible to read in the dark, for the display issues no light of its own.

Strong electromagnetic fields, as are generated by loudspeakers and the electric doors of a commuter train, cause the watches to go berserk, reported owners, and heat and cold can be disastrous to accuracy.

Watch companies solved some of those problems, but in the process they ended up creating new ones.

For instance, some manufacturers make an LED watch that lights the numerals at the flick of a wrist. Many owners have been irritated to discover that the watch lights inadvertently, needlessly draining the batteries. LCD watchmakers have built watches that feature a light to illuminate the display in the dark, but they require an extra battery and some button-pushing.

Timing events with an LED digital watch is difficult if the wearer has to keep a button pressed. And setting a digital watch usually involves more complex button-pushing or other manipulation than does setting a conventional watch.

These problems, too, were solved—for example, by designing the stopwatch function so users needed to press a button only once to start and once to stop. But bugs aside, the writer also doubted that people would be able to mentally adjust to the new technology.

Most people are unused to reading numerals rather than clock hands, and must make abstract calculations to figure out time intervals that are visually represented on the conventional watch face.

Of course, the digital watch did eventually succeed. In the 1980s, versions appeared with calculators, lunar phases, and foreign-language dictionaries. Today most people have a clock on their mobile phones, but the digital-watch industry is still going strong, with models created for everything from scuba diving to mountaineering.

So take that as a lesson when you encounter a new technology: the first incarnations might be clunky, but that's no real indicator of its staying power. tr

KRISTINA GRIFANTINI IS *TECHNOLOGY REVIEW*'S ASSISTANT EDITOR.

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